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Interaction Between Unmanned Vessels and COLREGS

Sebastian Öhland
Axel Stenman

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Author: Sebastian Öhland, Axel Stenman
Degree Programme: Degree Programme in Maritime Management - Turku
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Supervisor(s): Ritva Lindell

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Abstract

Autonomous or remote controlled vessels are a completely new subject, which are under development right now. There is a possibility that in a few years we will see unmanned vessels sailing in international waters. These vessels will still have to be following the navigational rules at sea. This thesis examines unmanned vessels and how they will interact with the current amendment of the International Regulations for Preventing Collisions at Sea (COLREGS), mainly part A and B.

The purpose of this thesis is to investigate how unmanned vessels interact with the navigational rules in COLREGS and if there will be any obstacles for implementing them in international waters. As research methodology we used a literature-based theoretical analysis in combination with a qualitative research.

Our conclusions are that compliance with COLREGS doesn't seem to be a huge problem for unmanned vessels. Most experts agree that compliance with COLREGS isn't a serious issue and the liability in case something happens is a more serious problem. Unmanned vessels have already been tested in a few projects where they have been able to follow the Collision Regulations and navigate safely without accidents. However, a few things such as look-out and responsibility might need clarification before unmanned vessels will start to appear on a larger scale.

Language: English Key words: unmanned, autonomous, vessel, COLREGS

Contents

1 Introduction

The fast development in technology and research has opened up new opportunities in many different industries. The shipping industry is no exception and during the last decades, there have been tremendous changes in the industry. Nowadays the crew onboard big cargo vessels are only a fraction of what it used to be and vessels are fitted with high-tech equipment to make navigation easier and safer.

During the last few years, people have started to talk about intelligent ships. Many considered it a crazy futuristic fantasy in the beginning, but today remote controlled and autonomous vessels are close to reality. Autonomous vessels have been figuring in the newspapers for a while now and there are already big ongoing maritime research projects in this area.

There is no doubt that unmanned vessels would result in a huge change for us seafarers as well as for the entire shipping industry. The idea of unmanned vessels raises many questions. How will unmanned vessels function? Are our jobs as mariners at risk? Whom to blame in case of an accident between unmanned vessels? Since we are going to be navigation officers one day, we chose to write our thesis about how unmanned vessels interact with the navigation rules at sea. In other words, the interaction between unmanned vessels and part A and part B of the International Regulations for Preventing Accidents at Sea (COLREGS).

1.1 Objective and research question

We both found unmanned vessels to be an interesting subject which we wanted to get a better understanding about. We decided to investigate how unmanned vessels interact with the navigational rules at sea as these are familiar to us and relevant to our education. The current version of COLREGS is from 1972 and even if it has been amended several times, the rules are quite old and not meant for today's technology. Unmanned vessels are a completely new subject and they are currently not mentioned anywhere in COLREGS or any other rules. The purpose of this thesis is to investigate how unmanned vessels interact with the navigational rules in COLREGS and if there will be any obstacles when implementing them in international waters. We will also look in to the issues that might arise when trying to implement unmanned vessels in international waters. The research question for our thesis reads:

"Is it possible to launch unmanned vessels in international traffic without violating the International Regulations for Preventing Collisions at Sea?"

1.2 Limitations

As this is such a broad subject we decided to limit our thesis to the rules contained in part A and part B in COLREGS. We will not take a stance if unmanned vessels should exhibit some new lights or shapes or use any special sound signals. Our main focus will be on a few crucial regulations that we see problematic for unmanned vessels. We will also only deal with the rules contained in COLREGS and not any additional national regulations. Technical and practical solutions for unmanned vessels will mainly be from the AAWA-project (Advanced Autonomous Waterborne Applications) proposed by Rolls-Royce and the EU-funded MUNIN-project (Maritime Unmanned Navigation through Intelligence in Networks).

1.3 Contexture

To be able to decide if unmanned vessels interfere with the Collision Regulations, one needs to have good knowledge about how unmanned vessels are supposed to work. Therefore, the first part after the introduction (chapter 2) is a theoretical description about unmanned vessels as proposed by the AAWA- and the MUNIN project.

Chapter 3 is a description of COLREGS for those who are unfamiliar to the subject. This chapter will not contain any deeper analysis about unmanned vessels and its only purpose is to give the reader a clearer picture of what the navigational rules at sea look like.

In chapter 4 we will present our research methodology and describe in detail how the research has been done. Chapter 5 contains our analysis of the rules in COLREGS and how they interact with unmanned vessels. In this chapter we will analyze the rules more deeply and discuss the material and theories that we have looked in to. Chapter 6 contains a qualitative research, where we have interviewed a couple of persons involved with unmanned vessels. The conclusions will be presented last in chapter 7.

1.4 Allocation of work

As we are two persons writing this thesis, we aimed to distribute the workload evenly between us. The research for the theoretical part about autonomous vessels is mainly done by Sebastian Öhland while Axel Stenman has studied COLREGS and written the theoretical part about COLREGS. The analysis, interviews and discussion of the rules and conclusions are done as a collaboration by both of us.

2 Theoretical part about autonomous and remote controlled vessels

2.1 Autonomous technology in other branches

Due to huge advances in science and computer engineering, autonomous vehicles have in the last decade gone from something that sounded like science fiction to something that most likely will be a reality in a couple of years. Many branches are already developing and using autonomous vehicles and the technology and computer power needed are getting better and better. The US military have been using remote controlled drones for a long time already and US Navy are already developing vessels that are autonomously controlled. (Rylander & Man, 2016). The car industry is currently a long way ahead of the shipping industry and many car manufacturers are already testing their driverless cars on the roads. Autonomous cars from several manufacturers are expected to hit the market in the beginning of 2020s. (Hars, 2016). Autonomous technology is also used in aircrafts, port terminals, railway systems and by law enforcement and firefighters in different places around the world. (Rylander & Man, 2016).

2.2 Ongoing maritime projects

Autonomous vessels are one of the newest things in marine technology and many large organizations and companies are currently researching and testing unmanned vessels. This spring the US Navy launched a fully autonomous, 132 feet long vessel that can operate for months in a row without a crew. The vessel is able to operate completely without human interaction and make collision avoidance decisions based on the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS). (Courtland, 2016). One of Chinas largest ship building companies plans to launch its first smart ship, a 38 800 dwt bulk carrier, in the year 2017. The smart ship will be using a whole ship information system, which enables data sharing between all systems on the ship. According to the developers, it will be designed for remote monitoring, support, management and control, using shore-based resources. (Young, 2016).

In the European Union there are currently two big projects concerning autonomous vessels. SARUMS is funded by the European Defence Agency (EDA) and stands for

Safety and Regulations for European Unmanned Maritime Systems. The objective of SARUMS, according to their mission statement, is to provide a safety framework for unmanned vessels that recognizes their operational usage, legal status and the needs of navies. (European Defence Agency). MUNIN is an abbreviation of Maritime Unmanned Navigation through Intelligence in Networks and it is an EU-funded project that consists of eight partners with various scientific and technical backgrounds. Compared to SARUMS, MUNIN focuses more on the practical side of the problem and aims to develop technical and practical solutions needed to make autonomous vessels a reality. (MUNIN, 2016).

The AAWA (Advanced Autonomous Waterborne Applications) project is a Finnish project funded by Tekes (Finnish Funding Agency for Technology and Innovation) which aims to explore the economic, social, legal, regulatory and technical factors that will be needed to make autonomous ships a reality. AAWA is made in collaboration with Finnish research institutions and leading members of the maritime cluster, such as Rolls-Royce and Inmarsat. (Jokoinen, et al.).

This paper will focus on the technical and practical solutions proposed by the AAWA project and the MUNIN project as well as the Lighthouse report made by the Swedish Maritime Competence Center. Other projects may have different solutions to certain problems but those will not be addressed here.

2.3 Technology

2.3.1 Levels of autonomy

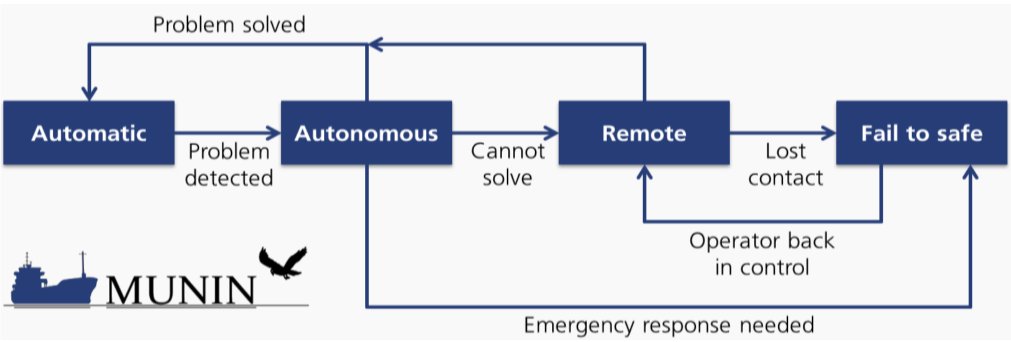
It is important to distinguish between remote controlled and fully autonomous vessels. A fully autonomous vessel will operate itself with the help of advanced computer systems and sensors and does not require human interaction. A remote controlled vessel on the other hand will be remotely controlled by a human somewhere on land. Researchers often talk about Level of Autonomy (LOA) and the most well-known scale to measure LOA is the Sheridans scale, which reaches from level 1, where a human is in charge of all decisions to level 10, where the system is completely automated. (Jokoinen, et al.)

Level	Description
10	The computer does everything autonomously, ignores human
9	The computer informes human only if it (the computer) decides so
8	The computer informes human only if asked
7	The computer executes automatically, when neccssary informing human
6	The computer allows human a restricted time to veto before automatic execution
5	The computer executes the suggested action if human approves
4	Computer suggests single alternative
3	Computer narrows aleternatives down to a few
2	The computer offers a complete set of decision alternatives
1	The computer offers no assistance, human in charge of all decisions and actions

Picture 1. Sheridan levels of autonomy. Rolls-Royce. (http://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf, page 7)

The autonomous vessel that Rolls-Royce are developing will probably be following a dynamic scale where the LOA ranges all the way from 1 to 10 on the Sheridans scale. On long oceangoing passages the computer will make the most of the decisions and the operator will monitor that everything goes according to the plan. If the situation require the operator can take over control and drive the ship remotely. In critical situations and port approaches the level of autonomy will be decreased and the vessel will be operated in remote control mode by a human. (Jokoinen, et al.).

The MUNIN project follows a similar line and defines an autonomous vessel as a combination of a remote controlled and automatic vessel. The vessel would normally be automatically controlled by a computer and if an unexpected situation occurs the computer will try to solve it by itself. If the system fails to solve the situation within given constraints it will request human intervention and if that's not possible it will go to *fail to safe* mode. (MUNIN, 2016).



Picture 2. MUNIN main operational modes. MUNIN. (http://www.unmanned-ship.org/munin/about/the-autonomus-ship/)

2.3.2 Automatic navigation system

The autonomous navigation system (ANS) that are mentioned in the AAWA paper will consist of different modules such as a route planning (RP) module, situational awareness (SA) module, collision avoidance (CA) module and a ship state detection (SSD) module. Each module will have its own task and when combined with dynamic positioning, propulsion system and a data link to the operator, it will form the whole autonomous navigation system. The SSD module or virtual captain (VC) module has the highest priority as it gathers information from all the other systems and decides what state the ship currently operates in. Depending on the other systems the VC decides if the vessel should be operated in autonomous, remote or fail to safe mode. Situational awareness is an important part of safely navigating a vessel. The situational awareness onboard an unmanned vessel has to be at least as good as the situational awareness onboard a conventional vessel. The SA module provides the CA module with information about the environment and nearby vessels, which the CA module then uses to assess the collision risk and take reactive collision avoidance. In contrast to the RP module which is used as a planning tool, the CA module is always active and makes decisions in real time according to the situation. (Jokoinen, et al.)

2.3.3 Sensors

The SA module will use different types of sensors to gather information from the environment and fuse them together. Current marine technology such as radar, GPS, AIS, ARPA and ECDIS can be used in combination with other type of equipment. Some kind of camera equipment will be necessary to detect nearby objects and create a similar view as an operator onboard normally would have. By using advanced camera equipment such as thermal cameras and high definition cameras and fusing them together, the operator can gain an even better view than he would have had if he actually was onboard the vessel. One problem with cameras is that they are weather dependent and doesn’t work as well in for example heavy rain or snow. This means that some other type of sensors such as radar or LIDAR has to be used in combination with cameras. The radars that ship nowadays are using are excellent at determining distances and they also offer a good field of view in most weather conditions. Their weak sides are at accurately detecting small objects and they doesn’t offer a good enough resolution to be used while navigating in small harbor areas or while berthing. (Jokoinen, et al.). Maritime radars usually operate on the S- or X-band which gives a good accuracy and range for a relative cheap price. By using radars that are operating on higher frequencies, such as the K- or W-band, it is possible to get a better resolution and a more detailed picture that can be used when navigating in smaller areas. The downside with using high-frequency radars are that they doesn't offer a good enough range to be used as a primary navigation tool and have to be used in combination with normal S- or X- band radars. High-frequency radars are currently in use in the automotive industry as parking assistance or blind spot detection. (Wolff). LIDAR stands for Light Detection and Ranging and it is a system that measures the time it takes the light to reach an object and reflect back and thus creates a very detailed 3D map of the environment. LIDAR is currently being used in Googles self-driving cars in combination with radar, cameras and ultrasound. (Google). The reliability of LIDAR in a marine environment has still to be tested as it is affected by weather conditions and consists of fast moving parts that can be prone to malfunction. Below follows a table that compares the different types of sensors and their weaknesses and strengths. The goal is to combine different types of sensors to minimize the errors and address all weaknesses. (Jokoinen, et al.).

	Visual HD cameras	IR cameras	Ship radar	Short-range radar	LIDAR	Sound
Spatial Accuracy	++	+	- -	-	++	- -
Field of view	+	-	++	-	+	++
Distance measurement	-	-	++	++	++	- -
Object identification	++	+	- -	- -	+	+
24H, all weather operation	- -	+	++	++	+ (?)	- (?)
Computational load of analysis	- -	-	++	++	- -	+
Marine robustness	++	++	++	+(?)	(?)	(?)
Price	++	-	+-	++	- -	+

Picture 3. Comparison of different sensors. Rolls-Royce. (http://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf, page 27)

2.3.4 Shore communication

Communication with the shore control center (SCC) has to be available all the time. If the computer system fails to solve a situation or if an unexpected situation occurs, the operator has to be able to take control of the vessel. It's not necessary to transmit all data when the ship is in full autonomous mode but if something happens the information should be available immediately. The amount of data that needs to be transferred grows with the amount of sensors that are used onboard. HD cameras and LIDAR produces significant amount of data which has to be taken into consideration. It is possible to reduce the amount of data that needs to be transferred by compressing the video and using lower picture resolutions. The SA module can also pick up the most important features that needs to be processed and leave out the rest. At open sea the ship will handle most situations by itself and the control center can receive a minimal amount of data to be able to supervise the vessel. (Jokoinen, et al.).

Different ways to transmit the data has to be considered. Faster connections are usually available near shore and the ship may be using 4G or some other mobile network when navigating near land. At open sea other alternatives, such as satellite or VHF has to be considered. The availability of bandwidth can be a problem in busy fairways if many nearby vessels require HD stream at the same time. By navigating a group of vessels, where one acts leader and handles most of the communication with the SCC this problem can be reduced. If the SCC loses all communication with a vessel the VC will change the state of the ship and it will go to fail to safe mode and lay still in the water until the connection returns. (Jokoinen, et al.).

2.4 Advantages with autonomous vessels

2.4.1 Economic advantages

The biggest incentive for autonomous vessels are probably the possible economical savings to be made by shipping companies. Bunker and crewing are two of the largest expenses in running a vessel and by moving the crew from the ship to a control center ashore and automating a lot of the tasks that normally would be made onboard the vessel, the total amount of personnel needed could be minimized. Maintenance would be done by a specialized maintenance crew in port and thus improving the efficiency of the work. The whole design of the vessel can also be rethought with better fuel economy in mind and things like accommodation, heating, water production, sewage treatment and other systems, whose only function is the comfort of the crew can be left out. This results in a more environmental-friendly ship that consumes less bunker due to its smaller weight and minimized air resistance. A lighter ship and reduced electricity consumption by the crew can increase the effectiveness of the ship by 15

%, according to Oskar Levander at Rolls-Royce. (Sjöström, 2015) The cost of a new vessel would probably rise at first but with more standardized systems and more experience gained the cost of a new vessel could over time be significantly less than the cost of a conventional vessel. A cash flow model based on a new build bulker made by the MUNIN project showed that autonomous vessels would be commercially viable under most circumstances. The profitability depends on the fuel price and the cost of a new build vessel. The base scenario, where the new building price increases with 10%, shows an increase in expected present value by 9,9 million USD over the ships lifetime. The best-case scenario, where the new building cost is decreased to 80% of the current average price of a new panamax bulker, generates an increase in present value by 29 million USD. (Kretschmann, 2015).

2.4.2 Safety

It is possible that autonomous vessels will improve the safety onboard the vessel and reduce the risk of an accident. About 75-96% of all maritime accidents are caused by some kind of human error. These accidents often occur due to fatigue, inadequate communication, hazardous environment, decisions based on faulty information or inadequate knowledge of the ship and its systems. (Rothblum). The autonomous vessel can reduce the human errors made by fatigue by offering a more comfortable work environment and longer rest periods for the operators. Machines are also better than humans at monitoring automated processes, process large amounts of data and following a set of rules made by humans. This makes the autonomous vessel more consistent than a human and may reduce mistakes made by the OOW in stressful situations. The cameras and sensors that are used are often also better than the human eye at detecting small objects in bad weather or restricted visibility and can in some cases be more effective than a traditional look-out. (Sjöström, 2015)

It is unclear if unmanned vessels will be of higher or lower interest for pirates. High ransoms are seldom paid for only cargo and the pirates need the crew for hostage. Removing the crew would not only make it safer for the crew but it could also make the vessel a less attractive target for pirates. In case of an attack the operator at the SCC could shut down the vessel and leave the pirates with an unmovable vessel in the middle of the ocean. No crew onboard also makes it easier for the military to go in and remove the pirates without the risk of civilians getting hurt. (Levander, 2016).

2.4.3 Other

The computer system on an unmanned vessel will be capable of making most of the decisions when the vessel is navigating at open sea, which gives the operator more time for other tasks. It might be possible for one captain to be in charge of a fleet of vessels instead of only one ship. This way the captain can concentrate on the tasks that he is trained to do, such as maneuvering the ship in demanding situations. The working conditions of the crew can also be improved and instead of spending months at sea they can go home to their families after the work day is finished. This can create new kind of jobs for highly skilled mariners who are looking for new challenges and want to go working ashore. It can also make maritime studies and research a more popular choice and help attract new generations to the maritime field. (Sjöström, 2015).

2.5 Challenges

2.5.1 Technical challenges

The technology to make unmanned vessels a reality already exists in several different branches. The automotive industry is currently leading the development of autonomous vehicles in civilian use and many solutions for autonomous ships can be taken from there. Sensor fusion is one of the key technologies for the safe navigation of autonomous vessels. Some sensors work better in certain circumstances and the goal is to combine them in an optimal way that address all weaknesses. To avoid faulty decisions based on wrong information the data needs to come from many different sources. Different manufacturers have different solutions on how to fuse the data together and the marine industry needs to figure out how to do this the optimal way onboard a vessel. Compared to cars, ships move much slower and will have much longer times to react to a danger and make avoidance decisions. On the other side, ships have much more inertia and react slower to steering commands. The harsh environment onboard a vessel also needs to be taken into consideration when choosing what technology should be used. (Jokoinen, et al.). Results from a test of an advanced sensor module (ASM) made by MUNIN, showed that the ASM was not safe enough to be used instead of a human. The purpose of the ASM is to maintain a lookout of the surrounding obstacles and environment to ensure that the vessel is able to comply with COLREGS and to navigate safely along its route. The only reason for the weak results was however insufficient range which could be improved with more advanced radars and fusion with other sensors. This is only one of the technical challenges that needs to be dealt with and tested before it can be used in real life. (Rylander & Man, 2016).

Another thing that needs to be considered is reliability of the machinery onboard an unmanned vessel. The ships that are built today need people onboard to handle the regular maintenance and occasional breakdowns. Unmanned vessels will still need maintenance and while scheduled maintenance can be done in port one needs to figure out what to do in case of a failure in one of the critical systems when the vessel is operating at open sea. New algorithms to assess the health of the machinery and other critical system can reduce the risk of something breaking down in the middle of a voyage. (Jokoinen, et al.). The ships would also have to be fitted with two completely separate machinery systems so that the secondary machinery system can be connected in case of a failure in the primary machinery system. Standardization is something that could made the ships more reliable and reduce the risk of a breakdown. Every new built ship is customized to fit the needs of the owner and reduce the cost for the shipyard. Oskar Levander from Rolls-Royce calls every ship a prototype and compares it to the aviation industry where they have standardized airplane models and navigation systems. By building every new vessel by the same standards a lot of the type errors that can be found on certain vessels could be eliminated over time. (Levander, 2016).

2.5.2 Regulatory and legal challenges

One of the biggest challenges with autonomous vessels may be to get the regulations to approve of unmanned vessels in traffic. International Maritime Organization (IMO) is a specialized agency of the United Nations, which is responsible of creating international conventions and regulations regarding maritime safety, security and environmental protection. Some of the most important conventions for shipping is:

- International Convention for the Safety of Life at Sea (SOLAS)
- International convention for the prevention of Pollution from ships (MARPOL)
- International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)

- Convention on the International Regulations for Preventing Collisions at Sea (COLREGS)

(IMO).

None of these conventions contains anything about unmanned vessels and some regulations may be challenging for unmanned vessels in international traffic. SOLAS chapter V for example, contains rules such as safe manning of ships, voyage planning, bridge visibility and the masters obligation to aid ships in distress. The STCW code handles issues such as safe watchkeeping and manning requirements. (Jokoinen, et al.). COLREGS may also have some challenging rules regarding unmanned vessels, which will be investigated further in this paper.

The first autonomous vessels will probably be sailing inside the national borders where the authorities can make changes in the national rules and regulations themselves. To get unmanned vessels approved on an international level can take a longer time, since the time perspective for new regulations through IMO is at least 10 years. (Sjöström, 2015).

The liability issues is another problem that needs to be considered. Who is at fault if the vessel runs aground or causes an accident when the vessel is operating autonomously. If the vessel is remote controlled and the operator is acting with negligence it will probably be handled the same way as it should be handled if the crew was onboard the vessel. Problems may arise if the autonomous system causes an accident which the operator cannot prevent. Who should be blamed if the connection with the SCC fails and the vessel collides with another vessel while operating in fully autonomous mode? Is it the owner/operators fault or should this be treated as a product liability issue where the shipbuilder or the software creators are responsible. (Jokoinen, et al.).

2.5.3 Safety issues

Before unmanned vessels can become a reality they need to be at least as safe as conventional manned vessels. There are many things to be considered regarding the safety of an autonomous vessel, such as: the ability to detect small object in the water, the ability to handle encounters with multiple ships, ability to navigate safely in coastal waters, ability to handle emergencies at sea and ability to handle breakdowns or errors in the system. If all systems working as they are supposed to, the safe navigation of the vessel should not be a problem. Nor should the ability to handle small problems or malfunctions be of any concern as the vessel would be monitored from the SCC at all times with the possibility for the operator to take control if anything unexpected happens. In the worst case scenario or if the vessel loses contact with the operator it should go to fail to safe mode and navigate to a safe place where the issue can be solved. The thing to remember is that autonomous vessels are something completely new and the systems that are going to be used needs to be tested over a longer period of time to prove their reliability. Therefore it is advisory to progress slowly and apply more and more automation in small steps so that the possible issues and risks can be addressed when they arise. (Jokoinen, et al.).

Cyber security is another concern that has to be taken into account. By connecting all systems and allowing the ship to be remote controlled from ashore, the risk for someone taking over the system increases. Instead of physically taking over the ship, the modern pirates can try to hack the system and remotely change its course or destination. The pirates may use the ship for ransom or as a weapon for possible terrorist attacks. The operation of the ship could also be disrupted by jamming of the GPS or AIS signals or communication with the SCC. Cyber security needs to be built in on all levels and methods like encryption, user identification, authentication and authorization, data protection, connectivity protection and activity logging can be used to prevent unauthorized use of the system. (Jokoinen, et al.).

While the autonomous vessel can reduce human-based errors there are also new risks that can arise when operating or monitoring a remote controlled vessel. Too many sensors can make it harder to distinguish what it important and lead to information overload by the operator. The problem is increased if the operator is monitoring multiple vessels at one time and switches back and forth from vessel to vessel. Long voyages when nothing happens can on the other hand lead to boredom and lack of attention and vigilance. Another thing to consider is the skills and training of the operators. With no crew onboard the vessels it becomes harder to get onboard training practice which means that the operators may not have had much experience of actually working onboard a vessel and can have difficulty of addressing certain problems from the SCC. It will also be necessary for the operators to have knowledge of how the system works and how the different sensors are affecting the automation. (Jokoinen, et al.).

The Lighthouse report about autonomous safety on vessels, highlights the importance of creating a user-centered design which helps to integrate the huge amount of ship information in a way that fits the goals, tasks and needs of the operators. This means that the system should be built in a way that it matches the capabilities of the operators and keeps them aware of what state the system is working in, while providing them with only the information that is needed. (Rylander & Man, 2016).

3 Theoretical part of COLREGS 1972

The 1972 Convention on the International Regulation for Preventing Collisions at sea (COLREGS) were adopted by the International Maritime Organization. Easily explained the collision regulations can best be described as the Rules of the Road at sea and is therefore often also abbreviated RoR.

3.1 History

There have been existing rules for the purpose of preventing collisions at sea for several hundred years. During the 1950s there was a series of collisions involving vessels equipped with radar. These collisions, along with the rapid increase of vessels fitted with radar, lead to revision of the rules. Eventually an International Conference on Safety of Life at Sea (SOLAS) was convened in 1960 by the Inter-Governmental Maritime Consultative Organization (later on named IMO). (Van Dokkum, 2012)

Later on, the Collision regulations from 1972 were adopted and entered into force in July 1977. The convention was designed to update and replace the COLREGS convention from 1960. Rules such as look-out requirements, risk of collision, safe speed and traffic separation schemes was now part of the Collision Regulations. The 1972 convention is still very much in force but have been amended several times during the last decades. (International Maritime Organization, n.d.)

3.2 Structure

COLREGS 1972 is divided into five parts and include 38 rules. In addition to these parts there is four annexes that contain technical details and requirements concerning lights and sound signals.

COLREGS 1972 is divided into five parts as following:

- Part A – General (Rules 1-3)
- Part B – Steering and Sailing (Rules 4-19)
- Part C – Light and Shapes (Rules 20-31)
- Part D – Sound and Light Signals (Rules 32-37)
- Part E – Exemptions (Rule 38)

In addition to these rules COLREGS include four annexes:

- Annex I – Positioning and technical details of light and shapes
- Annex II – Additional signals for fishing vessels
- Annex III – Technical details of sound signal appliances
- Annex IIII – Distress signals

Part B, which is the most extensive part, is also divided into three sections to clarify when different rules apply depending on visibility. (International Maritime Organization, n.d.)

Our main focus will be on a few regulations contained in Part A and Part B in this thesis since we're trying to find out how COLREGS currently relate to unmanned vessels. Rest of the parts, as well as a few rules in Part B, are of minor importance to us in our thesis and will therefore only be explained briefly.

3.3 Part A – General (Rule 1-3)

3.3.1 Application (Rule 1)

"(a). These Rules shall apply to all vessels upon the high seas and in all waters connected therewith navigable by seagoing vessels.

(b). Nothing in these Rules shall interfere with the operation of special rules made by an appropriate authority for roadsteads, harbours, rivers, lakes or inland waterways connected with the high seas and navigable by seagoing vessels. Such special rules shall conform as closely as possible to these Rules.

(c). Nothing in these Rules shall interfere with the operation of any special rules made by the Government of any State with respect to additional station or signal lights, shapes or whistle signals for ships of war and vessels proceeding under convoy, or with respect to additional station or signal lights or shapes for fishing vessels engaged in fishing as a fleet. These additional station or signal lights, shapes or whistle signals shall, so far as possible, be such that they cannot be mistaken for any light, shape or signal authorized elsewhere under these Rules.

(d). Traffic separation schemes may be adopted by the Organization for the purpose of these Rules.

(e). Whenever the Government concerned shall have determined that a vessel of special construction or purpose cannot comply fully with the provisions of any of these Rules with respect to the number, position, range or arc of visibility of lights or shapes, as well as to the disposition and characteristics of sound-signalling appliances, such vessel shall comply with such other provisions in regard to the number, position, range or arc of visibility of lights or shapes, as well as to the disposition and characteristics of sound-signalling appliances, as her Government shall have determined to be the closest possible compliance with these Rules in respect of that vessel." (Lloyd's Register, 2005)

In rule one all waters outside territorial waters are considered high seas by most countries and all waters connected therewith states that COLREGS always apply except when there are permitted local rules to take into account.

3.3.2 Responsibility (Rule 2)

"(a). Nothing in these Rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or by the special circumstances of the case.

(b). In construing and complying with these Rules due regard shall be had to all dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which may make a departure from these Rules necessary to avoid immediate danger." (Lloyd's Register, 2005)

The second rule covers the responsibility for the master, owner and crew to comply with the rules. A mariner should always comply with the rules and act with precaution if it is required to do so by the ordinary practice of seamen, or by special circumstances.

3.3.3 General definitions (Rule 3)

The third and last rule of Part A include General Definitions to clarify terms and words used in the Collision Regulations. (Van Dokkum, 2012)

3.4 Part B – Steering and Sailing (Rule 4-19)

The Steering and Sailing part of COLREGS is the most comprehensive one and is divided into three sections as following:

- Section I, rule 4 to 10, conduct of vessels in any condition of visibility
- Section II, rule 11 to 18, applies to vessels in sight of one another and
- Section III, rule 19, conduct of vessels in restricted visibility

3.4.1 Application (Rule 4)

Rule four states that all rules in section I apply in any condition of visibility.

3.4.2 Look-out (Rule 5)

"Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision” (Lloyd's Register, 2005)

This rule may seem straightforward and easy, but most collisions and groundings are due to wrong interpretation or disregard of this rule. There is a very big variance in how well-equipped vessels are today and how advanced the technology they use on board is. By all available means is a very tricky expression, it can mean everything from proper visual look-out with the naked eye to proper use of more difficult nautical instruments like radar and ECDIS (Electronic Chart Display and Information) (Van Dokkum, 2012). However, specifications regarding minimum standards for equipment, construction and operation of ships can be found in the International Convention for the Safety of Life at Sea (SOLAS), not in the COLREGS (International Maritime Organization, 1974).

It is important to keep in mind that the officer on watch (OOW) always carries the responsibility for ensuring that a proper look-out is being kept, even though the required number of people on the bridge can vary. (Van Dokkum, 2012)

3.4.3 Safe speed (Rule 6)

"Every vessel shall at all times proceed at a safe speed so that she can take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions…" (Lloyd's Register, 2005)

All vessels must take into account state of visibility, traffic density, maneuverability, weather, wind, draught and other factors that is crucial when determining a safe speed. The regulations do not include any information on what a safe speed is in knots, because this depends on the circumstances and conditions. The OOW is always accountable for determining a safe speed and will also have to justify his speed if an accident would occur. (Van Dokkum, 2012)

3.4.4 Risk of collision (Rule 7)

"Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt such risk shall be deemed to exist…" (Lloyd's Register, 2005)

As we mentioned earlier all available means may vary considerably depending on how well equipped and modern the vessel is. The OOW must be able to justify his choices and use all available means in a proper way to determine in good time if there is a risk of collision. (Van Dokkum, 2012)

3.4.5 Action to avoid collision (Rule 8)

Rule 8 covers actions that have to be taken to avoid collision. When possible, actions taken must always be positive, made in time and with due regard to good seamanship. Course alterations must also be large enough to be readily apparent either visually or on radar and result in safe passing. (Lloyd's Register, 2005)

3.4.6 Narrow channels and Traffic Separation Schemes (Rule 9 and 10)

Regulations on how to proceed in narrow channels, fairways and traffic separation schemes (TSS) can be found in rule 9 and 10 in the COLREGS (Lloyd's Register, 2005).

Further discussion of navigational rules like these do not seem essential for our purpose in this thesis. The collision rule amendments during the last decades have been more about clarifying existing regulations, than actually changing them. Even though unmanned vessels would result in a huge change for the shipping industry, we believe that the steering rules to a big part will remain the same.

3.4.7 Section II (Rule 11-18)

This section apply to all vessels in sight of one another and this is exactly what rule 11 states.

Rule 12-16 consists of steering actions to be taken in following situations:

- Two sailing vessels are approaching one another (rule 12)
- Overtaking (rule 13)
- Head-on (two power-driven vessels are meeting) (rule 14)
- Crossing situation (two power-driven vessels crossing) (rule 15)

Vessels, which is directed to keep out of the way of another vessel (according to the regulations), are called give-way vessel. Rule 16 states that actions taken by the give-way vessel shall always be early to keep well clear of another vessel.

The 17th rule contain information on how to act when you are the stand-on vessel. Vessel considered the stand-on vessel in a situation shall keep course and speed and only take action if it is required to avoid collision.

Rule 18 cover responsibilities between vessels if any other rule in COLREGS do not require otherwise. For example, a power-driven vessel underway shall keep out of the way of a vessel that is not under command. (Van Dokkum, 2012)

3.4.8 Section III (Rule 19)

This rule applies to vessels navigating in or near areas with restricted visibility and not in sight of one another. Section III, conduct of vessels in restricted visibility, only consist of this one rule. Proper radar use and to act cautiously are very crucial in these conditions. (Van Dokkum, 2012)

4 Research methodology

Empirical research can be divided into two categories. Qualitative research is about using language to approach and research, for example an interviewer having a structured and observe conversation with an informant. Quantitative research on the other hand is about investigating and processing statistical methods. In addition to the qualitative- and quantitative research design, you can also do an entirely literature-based dissertation. This is often the case when performing a theoretical analysis. (Patel, 2003)

4.1 Method

We decided to do a literature-based theoretical analysis to find out which rules in COLREGS that can be considered critical and difficult for unmanned vessels to comply with. This was done by first researching autonomous and remote controlled vessels and COLREGS. After that we compared how these two parts interacted with each other and looked at earlier researches and publications to determine which rules that are the most critical ones.

In order to answer our research question we decided to do a qualitative research by interviewing a number of people whose area of expertise is unmanned vessel.

A theoretical analysis and a few qualitative interviews was the best way to go to answer our research question. Unmanned vessel, and its interaction with COLREGS, is such a new topic that few people possess knowledge about it and therefore we had to exclude the quantitative research method.

4.2 Collection of data

By performing a literature-based analysis we got access to a wide range of earlier publications, articles and studies that dealt with the topic of our thesis. For greater validity we used a lot of different sources, tried to focus on big well-known maritime projects and adequate books and studies.

Through EBSCOhost academic database we tried searching with the keywords unmanned, autonomous, remote controlled, COLREGS and vessel. For example the search term ”unmanned AND vessel AND COLREGS” gave us five results. Even though we got matches using combination of these keywords, the search results were either not available for us or of minor importance to us in our thesis. Most of our sources we have found through the search engine Google, using the same keywords as mentioned above.

When performing the qualitative research we tried calling and sending out the questionnaire to eight persons that was involved in the MUNIN- or the AAWA project. Unfortunately, only three of these persons had time to answer our questionnaire - two persons involved in the MUNIN project and one person involved in the AAWA project.

5 COLREGS interaction with unmanned vessels

5.1 Overview

It is important to keep in mind that unmanned cargo vessels still are in a planning- and testing phase. The theoretical part for unmanned vessels in our thesis is based on several ongoing maritime projects and is only a projection of how these vessels most likely will function in the future.

Unmanned vessels are still not mentioned anywhere in the COLREGS or in any other International codes and conventions for that matter. Manned vessels will operate in the same waters as unmanned vessels and therefore it is very important that unmanned vessels also follow some set of navigational rules.

In our analysis on the interaction between COLREGS and unmanned vessels, we compare the latest amended version of COLREGS with the projection of how unmanned may function in the future. When and if shore-based controlled cargo vessels become reality, there may already be a new amendment of COLREGS in force.

Since vessels lacking a crew are not mentioned, nor defined in the Collision Regulations, we must base our analysis on the fact that shore-based controlled vessels have the same obligations as manned seagoing vessels. In that case, an unmanned cargo vessel underway will be treated exactly as a power-driven vessel underway.

5.2 Application (Rule 1)

Rule one of COLREGS states that all vessels upon the high seas or waters connected therewith have to comply with the Collision Regulations. In other words, all vessels sailing in sea areas beyond the limits of national jurisdiction will need to follow COLREGS. Inside national jurisdiction, there might be local rules in addition to COLREGS but the basics will be the same. It is therefore hard to argue against the fact that compliance to the COLREGS is a requirement even for vessels without a crew onboard. (Norris, 2013)

5.3 Responsibility of Master and Crew (Rule 2)

According to rule two, a mariner should always comply with the rules and act with precaution if it is required to do so by the ordinary practice of seamen or circumstances. Mariners describe “the ordinary practice of seamen” as normal seamanlike behavior under the circumstances where experience, knowledge and perception play a major role. The OOW could even be found guilty of neglecting the “ordinary practice of seamen” in a legal case if departure from the rules were considered required. (Van Dokkum, 2012)

The second part of this rule states that under special circumstances and to avoid immediate danger, a vessel may depart from these rules. Questions like; should a small pleasure craft enforce these rules in a close quarter stand-on situation, could arise. A larger vessel is obliged to follow the rules and give way for a smaller craft on her starboard side. However, the larger vessel is restricted by its poor maneuverability and slower reaction times and it might be considered “bad seamanship” for the smaller vessel to continue with its course and speed if safer options are available. (King, 2014).

It needs to be noted that only under special circumstances are deviations from the rules allowed and it is often decided afterwards in court if the vessel was following “the ordinary practice of seamen”. As this is such a fuzzy concept, it can be hard to define “ordinary practice of seamen” to a computer. As stated earlier these decisions are based on experience and knowledge of what is considered normal behavior. In any case, a close quarter situation should not arise when the vessel is operating in autonomous mode, as the system should be able to detect it in good time and hand over the control or alarm the operator. It should however be considered if and when the system is allowed to make deviations from the rules and what to do in case the operator isn’t available.

Liability in case of collision accident is a challenge that unmanned vessels may face. Oskar Levander, the Vice President of Innovation Marine at Rolls-Royce, concludes in his interview with the Swedish paper Sjofartstidningen that one of the biggest unsolved issues with unmanned vessels is the legal responsibilities between the parties involved. (Sjöström, 2015)

In the MUNIN-project, they came to a similar conclusion regarding responsibility:

"…In terms of liability, the biggest issue will concern the attribution of the existing ship master duties to the relevant and adequate persons involved in the operation of an unmanned ship" (MUNIN, 2016).

5.4 Definitions (Rule 3)

A vessel, according to the third rule called "Definitions" of COLREGS, includes all water crafts used or capable of being used as transportation on water. ”Power-driven" meaning any vessel propelled by machinery and "underway" that the vessel is not aground, at anchor or fastened to shore.

According to these statements, an unmanned vessel would be defined as a conventional power-driven vessel. However, it needs to be considered if a separate definition for unmanned or remote controlled vessels is needed, to make sure that they are included. A definition could also be useful if they are going to display some special lights or shapes, or to be referred to later in the rules.

5.5 Safe look-out (Rule 5)

The fifth rule of COLREGS states that a ship must maintain a proper lookout by sight and hearing for full appraisal of the risks of collision. Impliedly you get the understanding that a manned crew is required.

Vessels equipped with radar must use constant interaction between visual look-out and use of radar. Objects on the radar screen have to be compared with visual obtained information and vice versa. A visual lookout has to be conducted with the naked eye, with sunglasses or with the use of binoculars. In addition to these requirements all vessels shall also maintain a proper lookout by hearing at all time (Van Dokkum, 2012). Unfortunately, neither direct hearing nor visual lookout will be possible for a vessel lacking a crew onboard. The big question is if lookout on an unmanned vessel can be considered proper and if cameras and sound equipment are adequate substitutes to the human eyes and ears.

Danielle Sullivan Kaminski wrote in her article, "Who's to blame when no one is manning the ship", that a well-equipped unmanned vessel with advanced radar- and sonar systems might meet the requirements in rule five. Automated eyes and ears could prevent us from human errors arising when you are tired, sick or fatigue. The further technology advances, the more likely it is that the systems could meet the current standards. (Kaminski Sullivan, 2016).

As discussed above in the technical part of our thesis, long-range cameras and sensors are already very highly developed. The use of these may allow the shore-based controller to detect objects even better than the actual human eye. However, some of these sensors and cameras are new to the maritime field and they need to be tested over a longer period of time to prove their reliability. It can also be harder for the operator to get a good situational awareness when he or she is not actually onboard the vessel and solely has to rely on information gathered from different sensors. The design and layout of the SCC is also relevant here, as it should provide the operator with relevant data to make informed decisions based on what is really going on out there. Along with the liability issue, this is one of the most discussed issues regarding unmanned vessels and COLREGS and clarification of the look-out rule should be considered.

5.6 Safe Speed (Rule 6)

When determining a safe speed factors such as visibility, traffic density, maneuverability, draught, wind, current, characteristics of vessel and proper radar use should be taken into account.

Speed and heading will be changed automatically if needed on unmanned vessels. According to the Rolls Royce- and MUNIN project, vessels lacking a crew will be well equipped with the newest and most advanced technology. As long as unmanned vessels are able to take into account all the factors mentioned in rule number six for determining a safe speed, nothing really interfere with the regulations.

5.7 Vessels in sight of one other and definition of restricted visibility

Section II, rule 11 to 18, applies to vessels in sight of one another. According to the General Definitions (Rule 3), vessels shall be deemed to be in sight of one another only when they can observe each other visually (Van Dokkum, 2012). This raises the same question as in rule 5, are high technology cameras an adequate substitute to visual observation? Moreover, if the vessels need to be able to observe each other visually, does this means that every unmanned vessel should be treated as a vessel in restricted visibility and follow the rules in section III instead.

Section III only consists of rule 19, conduct of vessels in restricted visibility. The 19^{th} rule applies to vessels not in sight of one another in an area of restricted visibility. The term “restricted visibility” is defined in rule three as any condition in which the visibility is restricted due to fog, mist, snow, rainstorms, sandstorms or other causes. It can be difficult to determine whether the visibility is restricted or not. One reliable way to check the visibility is to measure the distance on the radar screen to an object when the object becomes visible for the naked eye (van Dokkum 2012, p.18-19). This would not be possible on an unmanned vessel since the vessel will be operated from ashore.

5.8 Navigation and interaction with other vessels

Unmanned vessels do not interfere directly with any demands in rule seven “Risk of Collision” or rule eight “Action to Avoid Collision” and therefore we do not see any big obstacles here. The technology used for securing a safe navigation is already considered reliable according to the maritime projects.

Most of the rules in section II are regulations on how to act in different situations, such as overtaking-, head-on- and crossing situations. Unmanned vessels do not interfere with these rules on any point since both the MUNIN- and the Rolls Royce project have planned to take into account these rules in their advanced autonomous navigational systems.

Rolls Royce are currently developing advanced system to enable unmanned vessels to navigate autonomously by the rules and avoid collisions. The RP-, SA-, CA- and SSA modules are all created to secure that unmanned vessels safely and autonomously can navigate at sea. How these modules are supposed to function was already discussed in our theoretical part about unmanned vessels, chapter two.

The US-based science and technology solutions company Leidos also announces that the submarine-hunting vessel in the DARPA project has completed a successful 42 days testing period at sea, including 101 different scenarios and are able to navigate safely in both narrow channels and traffic separation schemes. (Leidos, 2014).

5.9 Vessel not under command or restricted in ability to maneuver (Rule 18)

Some have been speculating about if rule 18 can be applied to unmanned vessels. If an unmanned vessel were labeled as “not under command” or “restricted in ability to maneuver”, other vessels would be obligated to keep out of their way. However, there is not much justification for this since unmanned vessels are designed to work and behave like manned vessels at sea. (Norris, 2013)

A vessel “not under command” is defined in rule 3 as a vessel which through some exceptional circumstance is unable to maneuver as required (Van Dokkum, 2012). We have to remember that both the MUNIN and the Rolls Royce project are trying to establish a system where unmanned vessels are able to navigate as manned vessels. The vessel is supposed to be unmanned all the time, so this cannot be considered an “exceptional circumstance”, and therefore we do not see any reason for an unmanned cargo vessel to be labeled “not under command”.

“Restricted in her ability to maneuver” is defined as a vessel which from the nature of her work is restricted to maneuver as required in the rules. For example, this rule can be applied to vessels engaged in dredging or towing operations (Van Dokkum, 2012). An unmanned cargo vessel will not be restricted in ability to maneuver in any ways due to her work. Manned seagoing cargo vessels are not labeled as “restricted in ability to maneuver” due to their daily work and unmanned vessels are designed to behave in the same way, so it is hard to find any justification for applying rule 18 in any way.

6 Interview with experts

As we did not get any clear answer to our research question, we decided to interview a few experts to get their opinions on the subject. We aimed to get at least one person from the MUNIN project and one person from the AAWA project to answer our questions. We made a questionnaire with questions that still remained unclear to us and sent it to several persons involved in each project. We also tried to get in contact with the persons through phone. From the MUNIN project, we got answers from Ørnulf Jan Rødseth, who is a senior scientist at SINTEF Ocean AS and from Wilko C. Bruhn who is a research associate at Fraunhofer CML in Germany. From the AAWA project Sauli Eloranta, head of innovation and technology at Rolls-Royce, was kind enough to answer our questionnaire.

Rødseth thought that unmanned vessels will exist in general international traffic in 10-20 years and in liner traffic between 2-3 countries in 3-5 years. Bruhn points out that there are already today unmanned vessels operating in for example ocean research and naval service. Commercially he thinks autonomous ships will go on trial runs in a few years, but these systems will be bound to specific routes and services, such as regular ferry links or offshore supply in the ocean energy or aquaculture sector. Eloranta had similar thoughts and guessed that unmanned vessels will be in limited international traffic between a few countries in about 5 years and in unlimited international traffic in ten years.

As for COLREGS, the agreement seems to be that this is not such a big problem. Rødseth stated that collisions will still occur and that there will always be different ways to interpret the rules and not all are following them. He does not see any obstacles with COLREGS rule five either and thinks high-tech sound equipment and cameras can be considered adequate substitutes to eyes and ears. The agreements with many legal specialists is that the issue can be solved with a suitable automated lookout-system (computer vision, integrated with sound, radar and AIS) with at least the same quality as a human look-out. This can be supported by a shore control center when and if necessary. Bruhn also commented that sensor systems are better than human senses on many levels and they can be even more suitable to carry out look-out tasks as they doesn't get distracted by other things. As an example, he gave that with infrared cameras you can achieve a much better sight at night.

According to Bruhn, there might not even be modifications required if sensor systems are approved to be equivalent to human cognition. He also points out that new technologies are appearing every day in various domains and legislation and jurisdictions are reacting towards these changes. He strongly doubts that this would not be the case for shipping also. Bruhn thought that the biggest problem with COLREGS is that the rules are designed for human interpretation and therefore can be difficult to comply with in complex situations. The big obstacle is that there is not always a clear binary response to every situation and this is not a simple task to teach a computer. Eloranta also considers machine-making decisions, in for example evasion situations, to be one of the main problems with following the COLREGS.

Rødseth on the other hand thought that the biggest problem with unmanned vessels will be liability in case of an accident. It is still not clear what type of liability will be applied and some specialists think that unmanned ships will have an increased objective liability for accidents, but the extent of this is currently unclear says Rødseth.

The subject of unmanned vessels is up for discussion in June 2017 at the Maritime Safety Committee 98 (MSC 98). According to Rødseth, these questions will probably be discussed on a more general level first and the proposal is that IMO starts to look at the broader set of international rules that may need to be updated. Sauli Eloranta states that to his understanding Finland and UK (in collaboration with numerous other flag states) already have submitted INF papers on autonomy to the IMO.

7 Conclusions

When it comes to legislation there is no doubt that unmanned vessels will cause major challenges for the shipping industry. Technology and research have opened up new opportunities for the industry but unfortunately, legislation is developing at a slower pace.

Autonomous vessels are still not mentioned in any International Codes or Conventions. In the Collision Regulations, you cannot find any information on what a safe speed is in knots, how many men or women a proper lookout requires or the distance in miles to another vessel when you are required to take action. Many of the regulations depend on the circumstances and therefore there is plenty of room for interpretation.

A ton of money has been spent on maritime projects trying to develop a reliable system that will enable vessels to operate autonomously. As we have mentioned earlier, they are striving for unmanned vessels to be able to navigate and behave like manned vessels. In other words, navigate and behave according to the COLREGS in sight of one another, in restricted visibility and in any condition of visibility.

If they are able to put together an unmanned vessel that are able to navigate and behave like manned seagoing vessels, there is not really a lot that need to be changed in the COLREGS. Mainly, we are talking about clarification of already existing rules. For example, visual observation and lookout by sight and hearing will not be possible for vessels lacking a crew onboard.

The liability in case of a collision accident is a major challenge that the shipping industry will face. Future accidents involving autonomous vessels will at least to a certain extent be caused by system failures. There are no clear answers to questions on liability for operations involving autonomous vessels yet. When can we blame the ship owner? Is it up to the shore based OOW navigator to make sure that there is not a system failure? Some say that it is up to the companies that created the systems to be held responsible, but then again others argue that the system creators are able to disclaim all liability for their product. On a manned vessel it is different, the master is in charge of both the nautical and technical operations. This can be anything from steering the ship to being responsible for the crew. All industries, for example autonomous cars and autonomous airplanes, where a computer driver replaces a human one face the same difficult liability question. However, ships automation will only be partial in the beginning, which may make the liability question a little bit easier to solve.

7.1 Answer to our research question

Our conclusion is that compliance with COLREGS does not seem to be a huge problem for unmanned vessels. Unmanned vessels have been tested in a few projects where they have been able to follow the Collision Regulations and navigate safely without accidents. A few things in COLREGS such as look-out and responsibility might need clarification before unmanned vessels can start to appear in big scale though. However, this is such a new subject that nobody really knows how it will be solved yet and many answers are only speculations of what might happen. It might be possible that a new version of COLREGS is in force when unmanned vessels becomes a reality or there might be some new rules for only unmanned vessels to follow. The agreement among the people we interviewed was that following COLREGS is not a huge problem and the lookout question can be solved with a suitable automated look-out system, which might even be more capable than a human to handle the look-out tasks.

To answer our research question "Is it possible to launch unmanned vessels in international traffic without violating the International Regulations for Preventing Collisions at Sea?" we will have to say that it is too early to say. There is nothing in COLREGS that completely contradict unmanned vessels but the problem is that COLREGS is written for manned vessels and a few things such as look-out or responsibility of the crew is left unclear when you take away the crew from the vessel. There are also some rules in COLREGS that leaves room for interpretation and some decisions should be based on human judgment, which is a hard thing to teach a computer.

7.2 Further research

As we made our thesis we came up with a few questions that is either under investigation or might be subject for further research:

- Are cameras and other sensors as good as human eyes and ears and can they replace a human look-out?
- Should the vessels be considered "in sight of each other" when nobody is onboard?
- How should the liability in case of an accident be handled, especially if there is a failure that prevents the operator to take command of the vessel?
- How to define "the ordinary practice of seamen" to a computer?
- How to handle complex situations which does not contain a single "correct answer" and requires human judgment to solve?
- Are the navigational rules outdated and is there time for a newer version of COLREGS?

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Annexes

Annex 1 - Questionnaire

Axel Stenman & Sebastian Öhland
Aboa Mare Maritime Academy, 2017

Questionnaire Unmanned Vessels Interaction with COLREGS

Name:
Title:
Employer:
Date:

1. How many years away are unmanned vessels from international traffic?

2. Do you think COLREGS is a problem for unmanned vessels in its current form? If yes, how do you think it will be solved?

3. What do you think the biggest obstacle concerning the collision regulations will be?

4. Do you see any obstacles with COLREGS rule 5 (look-out) and vessels in sight of one another? Can high-tec sound equipment and cameras be considered adequate substitutes to eyes and ears?

5. Have this subject been discussed in the IMO yet?