Autonomous sailing

Safety, liability and legislation.

Rotterdam Mainport University of Applied Sciences

Place, date: Rotterdam, 28 June 2016
Group 3

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1 Management summary

Introduction
The maritime sector has always been innovative. From canoes to sailing vessels to motor vessels. This is good development which will continue for the next generations to come (Hooydonk, 2014). The biggest error factor in shipping is the human element. Currently some 90% of all accidents at sea are largely contributed by human error (bowles-lang). For example, the Titanic, Costa Concordia, Herald of Free Enterprise, Flinterstar and Baltic Ace. In the calamities involving these vessels, the human factor is the major cause. This has always been the case, but now the technology allows for a new generation of vessels: autonomous vessels.

This report focusses on the safety, legislation and liability aspects of autonomous vessels and how autonomous ailing can be set up to comply with legislation. This report has been made by five students of the Mainport University of Applied Sciences. A comparison has been made between Manned and Unmanned sailing. Conclusions are that changes will have to be made to comply with legislation.

Conclusions
The project assignment has been divided in the main question and sub questions. These conclusions of the sub questions together has resulted in an answer to the main question.

Safety:
For the autonomous ships changes to assure a safe navigation for autonomous vessels must be applied. Technologically but also in the collision regulations. MUNIN recently brought out a final report where they state that Safety and security is levering the implementation of unmanned vessels. Human error plays a crucial part in most incidents. Based on an analysis of collisions and foundering scenarios for a MUNIN concept vessel, a decrease of collision and foundering risk of ten times was found to be possible on unmanned ships. This is mainly due to elimination of fatigue issues. Fire and explosions represent a relatively small part of all incidents and can be made much less risk prone through efficient extinguishing systems in fully enclosed spaces. Finally risks from cyber-attacks are an issue for unmanned ships. However, MUNIN states that software systems can be designed providing very high resilience against hacking. (MUNIN, 2015)

All the risks that come with autonomous sailing can be solved. Also the human factor will be removed which causes more than 90 % of all collisions and other accidents on sea. Statistically, the autonomous ships can improve global safety after removing the human factor, improving technology on board and introducing new COLREG rules.

When the human factor will be removed from the vessel the safety will improve. All human errors will no longer be an issue, there will be no human lives at stake during heavy weather or emergency situations. The only con is that there will be no human ability to respond in dangerous circumstances.

To improve safety of navigation the COLREGS would need to be adjusted. A separate regulation concerning unmanned vessels would clarify the use of navigation for manned vessels. This means that the unmanned vessel would carry distinctive lighting, day marks and their own rules for avoiding collisions. An unmanned vessel cannot give human assistance to other vessels in danger.
To maintain safety for all at sea, the COLREGS need some adjusting when the autonomous vessel will start sailing. The easiest way to do this is to make an autonomous vessel a different “type” of ship in the regulations. This way the COLREGS will stay the same for all manned vessels. And based on all the research, the autonomous vessel will be safer. This would mean that the COLREGS do not need to be adjusted for autonomous vessels concerning avoiding collisions. The rules are still applicable with modern day technology, even on autonomous vessels. The only important alteration is to make sure autonomous vessels can be identified. This means that the autonomous vessel would get characteristic lighting and day marks.

**Legislation & Liability:**

To make autonomous sailing comply with legislations, a lot of different regulations have to be adjusted. The changes do not have to be rigorous, probably just adding an amendment to the current regulations. (P&I, 2016)

To make autonomous sailing comply with legislation, liability and safety changes are required for the following things:

- Removing the human factor
- Improving technology
- Enhancing new COLREG rules
- many regulations need to be adjusted (see table 1)
- Making clear regulations for criminal liability

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*Table 1*
**Recommendations:**

**Safety**
To improve safety at sea when autonomous ships sail, changes in the COLREGS are needed, as well as a solution for communication between vessels. Also the maintenance on board is something that needs to change to avoid propulsion breakdown. Preventive maintenance and system redundancy will decrease the risks of propulsion breakdowns.

An option would be to have all autonomous ships carry white, blue, white lights. The contrast between white and blue can be clearly seen even during reduced visibility. During the day these ships could show a triangle pointing down, a ball and then a triangle pointing up to clearly state that they are autonomous vessels.

Communication between vessels could be done through satellite communication. This way a long distance communication can be acquired.

Filtering out the harmonic distortion in propulsion systems will make the systems more reliable.

A detection system that meets the requirements of the human eye could improve safety for unmanned vessels.

**Legislation**
To make autonomous vessels comply with legislation, a few changes have to be made. These changes are not major, but every seafarer should be aware of the new regulations. To make these changes in legislation, more research is required.

**Liability**

- **Liability regarding financial cost.**
  When it comes to financial liability, not many changes will be required. The fees resulting from incidents were usually going to the shipping company, this will not change for autonomous vessels. What will change in the financial part is that there will be more fees with unmanned vessel because criminal liability will not be possible in all situations. These fines will still be for the shipping company.

- **Liability regarding criminal acts.**
  In the criminal liability part there are some recommendations needed. In situations where on manned vessels a maritime license would be suspended, autonomous vessels could have their sailing license suspended instead. Meaning the vessel will not be able to sail for an amount of time.

Another punishment for manned vessel is imprisonment. This is also a punishment which needs to be changed or adapted. Because there is no crew on board autonomous vessels it could become unclear who is liable. When an unmanned ship is guilty of an oil spill the ship will be held responsible. In most of the situations the shipping owner or a designated person could be held liable for this punishment.
2 Preface

Autonomous sailing is a very hot topic but it is still in development and many aspects are yet unclear. For this reason, the RMU has given the assignment to investigate the aspects of safety, liability and legislation regarding the autonomous ships to a group of five students studying for the Bachelor of Maritime Operations. The stakeholder for this project will be the maritime sector. This project will be supervised by Mrs. Van der Drift.

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3 Introduction

The maritime sector has always been innovative. From canoes to sailing vessels to motor vessels. This is a healthy and innovative development which will continue for the next generations to come (Hooydonk, 2014). The biggest error factor in shipping is the human element. Currently 75-96% of all accidents at sea are largely contributed by human error (Bowles-Langle). For example, the Titanic, Costa Concordia, Herald of Free Enterprise, Flinterstar and Baltic Ace. In all the calamities involving these vessels, the human factor is the major cause. This has always been the case, but now the technology allows for a new generation of vessels: autonomous vessels. Many companies and organisations are researching the possibilities of autonomous sailing.

This report focusses on the safety, legislation and liability aspect of autonomous vessels and how they can be set up to comply with legislation. This report is made by five students of the Mainport University of Applied Sciences. During this project, a comparison will be made between Manned and Unmanned sailing. As a result, changes will have to be made to comply with legislation.

This project was supervised by Mrs. Van der Drift.

Problem Description:
Sailing is moving through the water from point A to point B. This track is divided in the following parts:
- Departure track in the departure port
- Coastal track
- High sea track
- Coastal track
- Arrival track in the arrival port

Currently the whole track from point A to point B is done by a crew on board vessels. This is expensive and the human factor is a big cause of accidents. A solution to minimize those accidents would be autonomous sailing.

On the high seas the only parties involved with the vessel will be the international parties such as the IMO and the flag state parties. This is the ideal starting place for autonomous vessels. There are no foreign regulations or restrictions to be taken into account.

By focusing on the high seas a guideline could be established concerning the regulations i.e. SOLAS, COLREGS. As of this moment the international regulations state that every vessel is required to have a minimum safe manning to be on board (Government). Meaning that unmanned vessels are prohibited yet.

The experience from the past shows that regulations follow the major incidents i.e. the SOLAS regulations are a result of the major incident known as the Titanic. (IMO, SOLAS)
Problem definition:  
There is no legislation for autonomous sailing concerning safety and liability.

Final objective:  
The final objective of this project is to create guidelines concerning the safety and liability factor so that autonomous vessels can comply with legislation.

Main question:  
How can the safety, liability and legislation be set up for autonomous sailing?

Sub questions safety:  
How can autonomous sailing improve the safety for global shipping? (Desk research)

Sub question Legislation:  
Which implementations or changes in legislation are required for autonomous ships? (Desk and field research, interview with P&I)

Sub question liability:  
What needs to be implemented concerning the liability in aspect of seagoing autonomous vessels? (Desk and field research, interview with insurance companies)

Project boundaries:  
To ensure specific, detailed and reliable data this project will be limited to the following boundaries:

- The high seas will be the only area to be researched for.
- This project will be limited to the sailing aspect of vessels.
- Only international regulations will be adhered.
- The project will be limited to international organizations and insurance companies.
4 Safety

Introduction:
Underground trains, cars and transport vehicles – they can all be operated unmanned already. Now the first of such projects has been launched for container shipping.

There are already unmanned projects going on in different sectors, container transport in terminals, unmanned vehicles and underground trains. Now Rolls-Royce and the European Commission-sponsored project “MUNIN”\(^1\) are among those developing concepts for unmanned ships as well.

The technology already exists to realize this project. Most of the tasks on the bridge of a ship are already automated. An autopilot can set the course, cruise control can maintain the speed, and radars and ship identification systems monitor the surroundings at sea and sound alarm if there is any danger. The final control of the ship can be made from a computer on the shore.

The benefits of this system seem clear. The space which is occupied by the bridge can be used to store extra cargo and the companies will save money on personnel expenses. Accidents by human error could be avoided with unmanned ships.

Not all of the tasks onboard of a ship can be automated. Tasks such as dealing with rust caused by the external exposure cannot be done onboard, reefer containers and dangerous goods cannot be checked every day with the current technologies on board the vessels. Furthermore the human ability to respond in emergency situations cannot be replaced by machines.

The safety of global shipping is mostly stated in SOLAS. Further regulations are set to enhance the safety onboard vessels. With autonomous vessels, some safety aspects of sailing will have to be adjusted to ensure that the autonomous ships will be just as safe if not safer than manned vessels. Regulations might be required to ensure that manned vessels and unmanned vessels will not get in conflict with one another. For this chapter desk research is required. Mainly MUNIN and SOLAS will be a guideline for this chapter.

The question to be answered in this chapter is: How can autonomous sailing improve the safety for global shipping?

This document is part of the assessment of the concept of an unmanned and autonomous bulk carrier as it has been developed in the project MUNIN. In particular it focuses on the external perspective on the innovation of an autonomous vessel. This chapter is divided in four sections which cover:

- Risks with the current way of seafaring
- Risks with a hybrid way of seafaring
- Risks with the autonomous way of seafaring
- A new guideline

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\(^1\) Maritime Unmanned Navigation through Intelligence In Networks
4.1 Risks with current way of seafaring

One of the main issues for unmanned sailing is if it improves safety for global shipping. In this chapter the main risks with the current way of seafaring will be listed and explained. The general idea of autonomous sailing is that it will improve safety issues. First of all the human error on board will no longer be an issue.

Human error:

About 75-96% of marine casualties are caused, at least in part, by some form of human error. Studies have shown that human error contributes to:
- 84-88% of tanker accidents
- 79% of towing vessel groundings
- 89-96% of collisions
- 75% of collisions
- 75% of fires and explosions
(Bowles-langley)

Human error is sometimes described as being one of the following: an incorrect decision, an improperly performed action, or an improper lack of action (inaction). (bowles-langley).

There are various different types of human errors.
The human error factor depends on the environment the human is placed in. There are three main factors which contribute in the human error.
- Technology
- Environment
- Organization

The human itself is not always the weak link. More often it is the way people perform in a certain environment.

If people cannot comply with the technology that they have to work with, mistakes are quickly made. For example, a valve that is placed inconveniently, making it difficult for a human to reach it.

The environment effects performance too. Not just the weather (seasickness), bad lighting, bad ventilation, temperature. But also the emotional state that a human develops in a certain environment, economically, or if people can’t comprehend together. This has a great effect on performance. A motivated and happy person will perform better than the ones who don’t.

A ship with humans sailing it, need a certain organization. This organization affects the human performance. If there is not an organized structure aboard, mistakes will be made. A strict hierarchical command structure can inhibit effective teamwork, whereas free, interactive communications can enhance it. Work schedules which do not provide the individual with regular and sufficient sleep time produce fatigue. Company policies with respect to meeting schedules and working safely will directly influence the degree of risk-taking behavior and operational safety.

(Rothblum, 1995)
4.2 Risks with hybrid way of seafaring

When autonomous vessels will start sailing, the global shipping will be divided in manned and unmanned sailing. This is the “hybrid way of seafaring”. This way of sailing will bring a number of risks with it. In this chapter these risks will be listed and worked out to make a clear view on the risks between manned and unmanned vessels.

Communication:

An unmanned vessel with the current communication procedures (i.e. VHF) would have difficulties to communicate with manned vessels. In situations where communication is required between a number of ships, this could cause unclear situations that used to be able to be solved through ship to ship communication. With autonomous vessels this has to be done by different means. VHF (very high frequency) is used for ship-ship communication, this is a technology that is used for close range communication. When autonomous vessels with shore based control centers want to communicate with other vessels, an option would be to do that trough satellite communication or new to be invented technologies. This is a long range communication device that sends signals through satellites, as shown in figure 1.2

![Figure 1.2](image)

**COLREGS:**

Every ship has to comply with the COLREGS (International Regulations for Preventing Collisions at Sea). These regulations are made to improve the safety of global shipping.

An autonomous vessel will not have persons on board to make sure these regulations are adhered to. This could cause risks concerning collision avoidance. When an unmanned and a manned vessel are in a situation where a collision is possible, certain measures need to be taken to avoid this. The current collision regulations do not include regulations for unmanned vessels, this is a critical point in unmanned sailing. A possible solution for this problem would be separate unmanned vessel regulations. When there are certain collision avoidance rules concerning unmanned vessels, it would improve the safety. A guideline would be to treat the unmanned vessels as a “restricted” vessel. If unmanned vessels have their own navigational lights, day marks and rules in navigation it would clarify the way to act in collision situations for a manned vessel.
Emergency situation assistance:

When a ship and its crew are in danger, surrounding vessels (when requested) are mandatory to help ships in need. An unmanned vessel is not able to give human assistance in situations like these.

4.3 Risks with autonomous way of seafaring

When ships will sail unmanned this will also bring risks with it. In this chapter the risks with the autonomous way of seafaring will be listed and explained.

Propulsion system breakdown:

When an unmanned vessel has a propulsion system breakdown, this could cause grounding or collisions. But, this seems to be the same as with a manned vessel. When a ship is not under command, it needs assistance to prevent grounding or collisions. For unmanned vessels it could be a solution to create a system that is fail-safe. As soon as the propulsion systems break down a signal could be sent to surrounding vessels or even shore based centers. This is comparable with a SART (Search and rescue transponder) or even EPIRB (emergency position indication radio beacon). Then a response from ground based stations could prevent grounding or collisions.

Not only a solution for a problem could solve this, but also preventive maintenance could lower the chance to even have a propulsion system breakdown. With improved maintenance routines and a redundant engine room a propulsion breakdown is much less likely to occur.

Another group that is researching in autonomous sailing came up with the redundancy idea. Redundancy means that critical systems or components are duplicated with the intention to decrease the affects off a default in the system. In case of an event the backup systems takes over. To improve the redundancy on board of unmanned vessels the “harmonic distortion” (Harmonic distortion means that the sinus of the electrical power is not a pure sinus. This will affect the efficiency off the electrical system and the lifetime of electrical components.) needs to be filtered out. To do this they came up with a few ideas: shaft generator, Hydrid propulsion (MAN, 2008), Low Loss concept (LLC) (wartisla, 2015)( see appendix I)

Failure in objective detection:

The human eye on the bridge is still a very reliable navigational help. It occurs that detection systems are unable to detect small objects, which the eye can detect. It is very important that unmanned vessels detection systems are reliable. This means that the current detection systems need improvement to make the navigation safer.

Another group that did research for detection concerning autonomous came up with a possible solution: “an advanced sensor module”, this is a system that meets the requirements of the human eye. Through camera detection and infrared vision this could be made possible. (See appendix II)
Hostile attacks (cyber-crime):

Electrical, automated systems are vulnerable for hackers. This is a great risk for unmanned ships. But the current day piracy is focused on hijacking the persons onboard. When there are no persons to hijack this enhances safety automatically. But it is possible that when autonomous vessels will sail, these ships become a target for another form of piracy, the hackers. A cargo ship is very valuable especially when it has cargo on board. Hackers may be interested in the value of these ships. Also an advanced form of terrorism may be a risk for these ships. If the controls of unmanned ships are hacked, terrorists could use the vessel for hostile attacks on humans. For these reasons it is very important that the security of the systems is ensured at all time.

Another group did research in piracy, they state that modern piracy in and around Asia is focused on fuel and not persons. They thought of a solution for using drones to ensure safety (see appendix III)

4.4 A new guideline

When it comes to improving safety for global shipping concerning autonomous ships, the main issue is the human factor. Furthermore, an improvement in technology aboard is required. But, the biggest issue in global shipping today, are the collisions. An autonomous vessel will have trouble following the COLREGS. Therefore, an idea could be to make adjustments to the COLREGS.

If an unmanned vessel gets its own rules, lights, signs and day marks, it would improve safety for navigation. A manned vessel can comply with these regulations and the chances of collisions are getting less. This is a guideline concerning the hybrid way of sailing. An unmanned vessel can for instance be treated as “restricted maneuverable”. It is important that the COLREGS get adjusted to avoid confusion and improve safety for navigation. There are a few regulations withholding an autonomous vessel from sailing in the COLREGS. These are the following:

Part A (General) states:
“For the purpose of these Rules, except where the context otherwise requires:”
Following with general definitions for all types of vessels. The autonomous vessel should be a general definition as well to clarify its means.

Part B (steering and sailing) states:
“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.”
Autonomous vessels will not have manned bridges to maintain a proper lookout. Any sort of exception should be made for autonomous ships.

Part C (lights and shapes) states:
“A power-driven vessel underway must display:

- A masthead light forward;
- If over 50 metres (164 ft.) length, then also a second masthead light aft and higher than the forward one; except that a vessel of less than 50 metres in length shall not be obliged to exhibit such light but may do so;
- Sidelights;
- A sternlight”
An autonomous vessel must also have navigational lighting to be identified. When an autonomous ship has its own lighting, other vessels can identify these ships as unmanned. Other than the usual navigational lights, one headlight, two for vessels larger than 50 meters. Two side lights, starboard green and portside red, and a white sternlight.

Other than the regulations stated above. The autonomous vessel needs to be in technological state so that it complies with the other regulations in the COLREGS. Such as taking action to avoid collision or being able to signal fog signs. It is important that the autonomous vessel complies with the regulations to maintain a safe navigation because there is no crew on the bridge, systems need to do the work or otherwise shorebased stations. This means that the technological equipment on the bridge must be at least as safe as the human. And as stated before, research proves that it will be safer. (page 12)

4.5 Conclusion

After this chapter, a conclusion can be made that there are a lot of risks concerning autonomous sailing. For just the autonomous ships and also for the hybrid way of seafaring. There will need to be some changes to assure a safe navigation for autonomous vessels. Technology wise but also in the collision regulations. MUNIN recently brought out a final report where they state that Safety and security is levering the implementation of unmanned vessels. Human error are a crucial part for most incidents. Based on an analysis of collisions and foundering scenarios for a MUNIN concept vessel, a decrease of collision and foundering risk of ten times was found to be possible on unmanned ships. This is mainly due to elimination of fatigue issues. Fire and explosions represent a relatively small part of all incidents and can be made much less risk prone trough efficient extinguish systems in fully enclosed spaces. Finally risks from cyber-attacks are an issue for unmanned ships. However, MUNIN states that software systems can be designed providing very high resilience against hacking. (MUNIN, 2015)

All the risks that come with autonomous sailing can be solved. Also the human factor will be removed which cause 75-96 % of all collisions and other accidents on sea. Statistically, the autonomous ships can improve global safety by removing the human factor, improving technology on board and enhancing new COLREG rules.

When the human factor will be removed from the vessel the safety will improve. AI human errors will no longer be an issue, there will be no human lives at stake during heavy weather or emergency situations. The only con is that there will be no human ability to respond in these situations yet.

To improve safety of navigation in hybrid sailing the COLREGS would need to be adjusted. A separate regulation concerning unmanned vessels would clarify the use of navigation for manned vessels. This means that the unmanned vessel would carry distinctive lighting, day marks and their own rules for avoiding collisions. An unmanned vessel cannot give human assistance to other vessels in danger.

To maintain safety for all at sea, the COLREGS need some adjusting when the autonomous vessel will start sailing. Probably the easiest way to do this is to make an autonomous vessel a different “type” of ship in the regulations. This way the COLREGS stay sort of the same for all manned vessels. And based on all the research, the autonomous vessel will be safer. This would mean that the COLREGS don’t need to be adjusted for autonomous vessels concerning avoiding collisions. The rules are still applicable with modern day technology, even on autonomous vessels. The only important alteration is to make sure autonomous vessels can be identified. This way manned vessels can consider their actions. This means that the autonomous vessel would get characteristic lighting and daymarks.
5 Legislation

Introduction:
Certification of ships is done following the laws and regulations set for them. When autonomous ships will start sailing certain certifications will need to be adjusted or dropped and new certifications might have to be made. In this chapter the certifications that will not be applicable for autonomous vessels, such as the safe manning certificate will be inspected and alternative options will be laid out to enhance the safety of all ships at sea. This chapter will be filled by mostly desk research and some field research (see appendix IV & V for interview) will be used to clarify the complications.
The question to be answered in this chapter is: Which implementations or changes in legislation are required for autonomous ships?

Legal basis:
Legislation and international rules will obviously be a problem for unmanned ships, as will insurance. However, where legislation is concerned, there are already two situations that are relatively easy to handle:

Unmanned operation only in international waters, which is being done by the MUNIN project. Doing so would only require the approval of the flag state. This solution would require crew to be on board during passage in national waters. (Munin, 2015)

Unmanned operation only in national waters, e.g. short-sea shipping or supply services in the offshore industry. In this situation the coastal, port and flag state would be one and the same and approval of operation would be up to this state alone.

To allow operation in international traffic more generally, where ports in different countries are called on, international legislation would need to be harmonized.
The international trust will have to be gained by proper documentation of safety and reliability (Matinetek, sd)

5.1 Regulations that are in conflict with autonomous sailing.

SOLAS

- SOLAS Chapter IV radio communications

Regulation 12 watches:
“Every ship, while at sea shall maintain a continuous watch:

.1 on VHF DSC channel 70, if the ship, in accordance with the requirements of regulation IV/7.1.2, is fitted with a VHF radio installation;

.2 on the distress and safety DSC frequency 2,187.5 kHz, if the ship, in accordance with the requirements of regulation IV/9.1.2 or 10.1.3, is fitted with an MF radio installation;

.3 on the distress and safety DSC frequencies 2,187.5 kHz and 8,414.5 kHz and also on at least one of the distress and safety DSC frequencies 4,207.5 kHz, 6,312 kHz, 12,577 kHz or 16,804.5 kHz, appropriate to the time of day and the geographical position of the ship, if the ship, in accordance
with the requirements of regulation IV/10.2.2 or 11.1, is fitted with an MF/HF radio installation. This watch may be kept by means of a scanning receiver;

.4 for satellite shore-to-ship distress alerts, if the ship, in accordance with the requirements of regulation IV/10.1.1, is fitted with an INMARSAT ship earth station.

2 Every ship, while at sea, shall maintain a radio watch for broadcasts of maritime safety information on the appropriate frequency or frequencies on which such information is broadcast for the area in which the ship is navigating.

3 Until 1 February 2005 or until such other date as may be determined by the Maritime Safety Committee, every ship while at sea shall maintain, when practicable, a continuous listening watch on VHF channel 16. This watch shall be kept at the position from which the ship is normally navigated.”

- SOLAS chapter V Regulations.

Regulation 11 ship reporting systems:

“7. The master of a ship shall comply with the requirements of adopted ship reporting systems and report to the appropriate authority all information required in accordance with the provisions of each such system.”

As many of the communication equipment have limited range (VHF MF/HF NAVTEX) a continuous watch cannot be maintained on autonomous vessels.

MCA (Maritime and Coastal Agency) Guidance:

“3. Ships to which a mandatory ship reporting system applies should report to the shore-based authority without delay when entering and, if necessary, when leaving the area covered by the system. A ship may be required to provide additional reports or information to update or modify an earlier report.”

When there will be no master onboard a vessel, there can be no response on the VHF. This can be done through e-mail or Inmarsat Phone. This means that new/ different certified communication equipment

Regulation 14 – ships manning.

“1. Contracting Governments undertake, each for its national ships, to maintain, or, if it is necessary, to adopt, measures for the purpose of ensuring that, from the point of view of safety of life at sea, all ships shall be sufficiently and efficiently manned.”

“2. For every ship to which chapter I applies, the administration shall:

.1 establish appropriate minimum safe manning following a transparent procedure, taking into account the relevant guidance adopted by the organization*; and

.2 issue an appropriate minimum safe manning document or equivalent as evidence of the minimum safe manning considered necessary to comply with the provisions of paragraph 1.”

Here is clearly stated that every vessel must be manned. This regulation should be adjusted so that unmanned vessels may sail legally.
Regulation 22 - Navigation Bridge visibility (3)

“3. On ships of unconventional design which, in the opinion of the Administration, cannot comply with this regulation, arrangements shall be provided to achieve a level of visibility that is as near as practical to that prescribed in this regulation.” (https://mcanet.mcga.gov.uk, sd)

As unmanned vessels do not require a bridge or necessary means for a practical visibility this regulation needs to have an amendment for autonomous ships.

Regulation 33 – Distress situations Procedures and obligations.

“1. The master of a ship at sea which is in a position to be able to provide assistance on receiving information from any source that persons are in distress at sea, is bound to proceed with all speed to their assistance, if possible informing them or the search and rescue service that the ship is doing so. This obligation to provide assistance applies regardless of the nationality or status of such persons or the circumstances in which they are found. If the ship receiving the distress alert is unable or, in the special circumstances of the case, considers it unreasonable or unnecessary to proceed to their assistance, the master must enter in the log-book the reason for failing to proceed to the assistance of the persons in distress, taking into account the recommendation of the Organization, to inform the appropriate search and rescue service accordingly.” (https://mcanet.mcga.gov.uk, sd)

MCA Guidelines (1)

“1. Reg. 33 applies to all ships.” (https://mcanet.mcga.gov.uk, sd)

This regulation cannot be followed on unmanned vessels due to the fact that there will be no captain onboard the vessel.

COLREGS

Part A - General

“Rule 1 states that the rules apply to all vessels upon the high seas and all waters connected to the high seas and navigable by seagoing vessels.” (http://www.imo.org, sd)

There is no category/ rules for unmanned vessels in the collision avoidance rules.

Ship Registration convention:

Article 9 manning of vessels.

“1. Subject to the provisions of article 7, a State of registration, when implementing this Convention, shall observe the principle that a satisfactory part of the complement consisting of officers and crew of ships flying its flag be nationals or persons domiciled or lawfully in permanent residence in that State” (http://unctad.org, sd)

“2. Subject to the provisions of article 7 and in pursuance of the goal set out in paragraph 1 of this article, and in taking necessary measures to this end, the State of registration shall have regard to the following&
(a) the availability of qualified seafarers within the State of registration,
(b) multilateral or bilateral agreements or other types of arrangements valid and enforceable pursuant to the legislation of the State of registration,
(c) the sound and economically viable operation of its ships.” (http://unctad.org, sd)

As no crew will be onboard, the autonomous vessel cannot comply with this convention.
UNCLOS

**Article 94 - Duties of the flag State**

“3. Every State shall take such measures for ships flying its flag as are necessary to ensure safety at sea with regard, inter alia, to:
(a) The construction, equipment and seaworthiness of ships;
(b) The manning of ships, labour conditions and the training of the crew, taking into account the applicable international instruments;
(c) The use of signals, the maintenance of communications and the prevention of collisions.”

“4. Such measures shall include those necessary to ensure:
(b) that each ship is in the charge of a master and officers who possess appropriate qualifications, in particular in seamanship, navigation, communications and marine engineering, and that the crew is appropriate in qualification and numbers for the type, size, machinery and equipment of the ship;
(c) that the master, officers and, to the extent appropriate, the crew are fully conversant with and required to observe the applicable international regulations concerning the safety of life at sea, the prevention of collisions, the prevention, reduction and control of marine pollution, and the maintenance of communications by radio.”

**ISM code**

6.2. The Company should ensure that each ship is manned with qualified, certificated and medically fit seafarers in accordance with national and international requirements.

The ISM code says that every company (ship) requires a SMS (safety management system)

5.2 **Regulations that need to be adjusted/removed from the current legislation.**

Due to the current regulations, it is not allowed to sail a ship without a crew. These regulations are listed in the previous paragraph. This paragraph contains why those regulations do not allow autonomous vessels to sail, and what has to be changed.

For this paragraph, the “unmanned ships” will be divided in to two groups.
1. Remote controlled vessels and
2. Autonomous vessels.

The remote controlled vessels will be controlled from a remote location by a shore based human crew. The data used by the shore based crew will be sent from the ship to the shore based control Centre.

The autonomous vessels are smart vessels and depend on pre-programmed instructions, or artificial intelligence. These vessels will collect and process their data themselves. These vessels make decisions about a navigation and form an independent opinion.

Apart from the fully autonomous vessels, there are also semi-autonomous vessels, these make the routine decisions by the programmed instructions, but are supervised, corrected or overridden by humans ashore.
The regulations that need adjusting:

**SOLAS**

- **SOLAS Chapter IV radio communications**
  This regulation states that every ship should maintain a continuous watch on various channels. If there is no crew onboard, this is not possible with the current equipment because the current equipment is always controlled by a crewmember on board. For this regulation there has to be a change in equipment, regulation or both.

- **SOLAS chapter V Regulations.**
  This regulation states that the master of a ship should comply with the requirements of adopted ship reporting systems and report to the appropriate authority.
  When there is no master or crew on board, this is not possible in the current way.
  For autonomous vessels regulations/equipment would have to be amended, so the ship is able to send the information via a different system by itself, for example automated E-mail system.
  For remote controlled vessels, regulations/equipment have to be amended.

- **MCA (Maritime and Coastal Agency) Guidance:**
  This regulation states that every ship to which a mandatory ship reporting system applies should report to the shore-based authority without delay when entering and, if necessary, when leaving the area covered by the system.
  When there is no master or crew on board, this is not possible in the current way.
  For autonomous vessels, equipment and regulations have to be amended, for example by automated new communication systems
  For remote controlled vessels, regulations have to be amended. For example, that a shore based captain is allowed to take over this obligation.

- **Regulation 14 – ships manning.**
  This regulation states clearly that every vessel should be manned. Of course, this is not possible with unmanned vessels.
  For autonomous vessels, regulations have to be amended.
  For remote controlled vessels, regulations have to be amended. For example, that automated systems are allowed to take over the duties of the crew.

- **Regulation 22 - Navigation Bridge visibility (3)**
  This regulation states that each ship should achieve a level of visibility that is as near as practical to that prescribed in the regulation.
  When there will be no crew on board, a “bridge” may not be required.
  For autonomous vessels, regulations and equipment have to change. For example, that cameras are allowed to take over this obligation.
  For remote controlled vessels, regulations have to be amended. For example, that cameras are allowed to take send the view to the shore based crew.

- **Regulation 33 – Distress situations Procedures and obligations.**
  This regulation states that a master of a ship which is in a position to be able to provide assistance on receiving information from any source that persons are in distress at sea, is bound to proceed with all speed to their assistance, if possible informing them or the search and rescue service that the ship is doing so.
  For autonomous vessels, regulations have to be amended, and new technologies have to be introduced. For example, that the autonomous ship is proceeding as fast as possible to the distress location, and is able to release lifebuoys/liferafts automatically.
For remote controlled vessels, regulations have to be amended. For example, that the shore based crew takes over the obligations of the crew.

**COLREGS**

- Part A – General
  This regulation states that the rules apply to all vessels upon the high seas, and all water connected to the high seas and navigable by seagoing vessels.
  There is no category for unmanned vessels.
  For autonomous vessels, an example would be to make an addendum for autonomous vessels, including their own navigational lights
  For remote controlled vessels, an example would be to make an addendum for remote controlled vessels, including their own navigational lights. (Different lights from autonomous vessels)

Ship Registration convention:

- Article 9 manning of vessels.
  This convention states that a satisfactory part of the crew of the ship are nationals of the flag state of the flag the ship is flying. It also states that the flag state should take necessary measures to have qualified seafarers. As no crew will be on board, the unmanned vessels cannot comply with this regulation.
  For autonomous vessels, regulations have to be amended, because there will be no crew on board.
  For remote controlled vessels, regulations have to be amended. For example, that the shore based crew should consist of a satisfactory part of nationals of the flag state.

**UNCLOS**

- Article 94 - Duties of the flag State
  This convention states that every flag state shall take such measures for ships flying its flag are necessary to ensure safety at sea with regard to: The manning of ships, labor conditions and the training of crews. It also states that each ship should be in charge of a master and officers who possess appropriate qualifications.
  Because no crew will be on board, unmanned ships cannot comply with this regulation.
  For autonomous vessels, regulations have to be amended.
  For remote controlled vessels, regulations have to be amended. For example, make an addendum for shore based crew.

**ISM code**

6.2.
This regulation states that the company should ensure that each ship is manned with qualified, certified and medically fit seafarers.
When there will be no crew on board this is not possible.
For autonomous vessels, regulations have to be amended.
For remote controlled vessels, regulations have to be amended. For example, make an addendum which contains the qualifications of the seafarer.
5.3 Creating a guideline to enable autonomous vessels to comply with legislation.

In this paragraph a guideline will be created to enable autonomous vessels to comply with legislations. For each regulation named in the previous paragraph an amendment or new regulation will be made.

SOLAS

- SOLAS Chapter IV radio communications
According to this regulation, every ship should maintain a continuous watch on various channels.

Autonomous vessels are required to report and to maintain a continuous watch. This can be done by different means i.e. EGC Inmarsat phone, E-mail or by a shore based crew.

- SOLAS chapter V Regulations.

Regulation 11 ship reporting systems:
This regulation states that the master of a ship should comply with the requirements of adopted ship reporting systems and report to the appropriate authority.
Autonomous vessels are allowed to take part to the reporting systems by automated communication systems, such as automated e-mail system or EGC.

MCA (Maritime and Coastal Agency) Guidance:
This regulation states that every ship to which a mandatory ship reporting system applies should report to the shore-based authority without delay when entering, and, if necessary, when leaving the area covered by the system.
Autonomous vessels are allowed to take part to the reporting systems by automated communication systems, such as automated e-mail system or EGC.

Regulation 14 – ships manning.
This regulation states clearly that every vessel should be manned, from the point of view of safety of life at sea.
Autonomous vessels are allowed to sail without a crew on board, the safety duties such as firefighting, responding to distress calls, have to be taken over by automated systems.

Regulation 22 - Navigation Bridge visibility (3)
This regulations states that a ship should achieve a level of visibility that is as near as practical to that prescribed in the regulation.
Autonomous vessels are allowed to attain a level of visibility that is as near as practical to that prescribed in the regulation by cameras or other automated systems.

Regulation 33 – Distress situations Procedures and obligations.
This regulation states that a master of a ship which is in a position to be able to provide assistance on receiving information from any source that persons are in distress at sea, is bound to proceed with all speed to their assistance, if possible informing them or the search and rescue service that the ship is doing so.
Autonomous vessels are allowed to respond to a distress call by automated systems, if possible, proceed with all speed to their assistance to the position of distress.
**COLREGS**

- Part A – General

This regulation states that the rules apply to all vessels upon the high seas, and all water connected to the high seas and navigable by seagoing vessels.

Autonomous vessels should have their own navigational lights and day marks.

**Ship Registration convention:**

**Article 9 manning of vessels.**

This convention states that a satisfactory part of the crew of the ship are nationals of the flag state of the flag the ship is flying. It also states that the flag state should take necessary measures to have qualified seafarers.

Autonomous vessels are exempted for this regulation.

**UNCLOS**

**Article 94 - Duties of the flag State**

This convention states that every flag state shall take such measures for ships flying its flag are necessary to ensure safety at sea with regard to: The manning of ships, labor conditions and the training of crews. It also states that each ship should be in charge of a master and officers who possess appropriate qualifications.

Autonomous vessels are exempted for this regulation. But, the flag state should take such measures necessary to ensure safety, proper, qualified crews at the shore based control center.

**ISM code**

6.2.

This regulation states that the company should ensure that each ship is manned with qualified, certified and medically fit seafarers.

Suggestion: an amendment should be made.

Autonomous vessels are exempted for this regulation, but the company should ensure that each ship is supervised by certified, and qualified shore based crew.

### 5.4 Conclusion

To make autonomous sailing comply with legislations, a lot of different regulations have to be adjusted, see the table 1. The changes do not have to be major, probably just adding an amendment to the current regulations. (P&I, 2016)

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<th>Regulation</th>
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*Table 1*
6 Liability

Introduction:

Certain legislations and procedures are followed when an incident occurs with a manned vessel involved. The case will be researched and through the findings the responsible group will be held liable by law. When autonomous ships will sail the seas certain aspects would become unclear. In this chapter a closer look will be taken at which aspects would become unclear and what could be implemented to prevent those unclear circumstances. Desk and field research will both have to be used to come to solid conclusions (see appendix IV-VI).

The question to be answered in this chapter is: What needs to be implemented concerning the liability in aspect of seagoing autonomous vessels?

6.1 Legislation and procedures that need to be followed when an incident occurs.

Incidents occur at sea. Certain measures are taken when this happens. This subchapter will describe how the Tuchtcollege and the insurance companies will react to these incidents.

The captain and ship officers are bound by the verdict of the Tuchtcollege if they neglect to follow good seamanship. The Tuchtcollege has rules and procedures that need to be followed. These rules and procedures are as follows:

- Ships incident occurs
- Request by Minister of Inspectie Leefomgeving en Transport or by concerned party to investigate
- The chairman can decide if preliminary investigation is required
- After the preliminary investigation the inquiry can be discarded
- The chairman decides if the inquiry is discarded. If so, the concerned party or the minister can resist and force the inquiry to continue
- Vocal interrogations with all involved individuals
- The charge is made
- Verdict is given

(Wet zeevarensten artikel 55, sd)

When the verdict has been made, the liable party’s insurance company will have to compensate.

A claim will be initiated by the Company in accordance with the Club rules and regulations upon receipt of all relevant information and documentation from the vessel. Depending upon the nature of the claim, the services of a surveyor or Club correspondent may be employed.

It is important to note that Owners must first pay the costs of any claim themselves and will only recoupate their loss, minus any deductible, once a claim has been compiled and accepted by the Club. It must be stressed that in order for the Owners to bring about a successful claim, every aspect of the incident must be correctly and fully documented.
6.2 Necessary adjustments for unmanned vessels.

Concerning the liability during any incidents between vessels on sea there will be some parts which will become unclear. Liability can be divided in two parts, financial liability and criminal liability. The financial liability part will not be much different from the situation nowadays with manned vessels, but the criminal liability will need a closer look and some changes like imprisonments or other punishments.

Financial Liability.

At this moment when a collision with two manned vessels occurs, the investigation will determine who made any mistakes or violated any rules. Then will be determined who will be liable for the costs of the damage made during the collision. Normally with manned vessels the shipping company will receive the claims of the damage and the insurance company will have to compensate this claim. When a vessel is sailing unmanned and causes an incident, the vessel will still be liable for this situation. Whether there is a crew onboard the ship or not the ship will be liable for this accident and the shipping company will have to pay for the damage made. (Heijboer, 2016)

The consequences of an accident or a collision with an unmanned vessel will be much bigger because there will be no people in the area who can jump in and take over the machines. This will have a big impact on the costs of the incident. Because of this reason insurance companies will have to think more than once before they want to insure an unmanned vessel.

A big factor in the COLREGS is the seamanship. Part B, rule 8a: 
“(a) Any action to avoid collision shall be taken in accordance with the Rules of this Part and shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship.” (IMO)

When the autonomous ships start sailing the seas this is a rule which is incompatible for the autonomous ship. Like the rule is describing, ships should take action and may violate the rules so a collision will be avoided. The problem with this rule is that machines are not able to apply good seamanship. They can be programmed to comply with the COLREGS. There can be an emergency plan for different situation when the CPA is getting to close. (Buijsse, 2016)

Criminal Liability.

When a vessel causes a situation where someone needs to be held liable for the damage done to the surroundings the captain will be the person who will be held liable for this. A situation may occur where the captain of the vessel is punishable by a prison sentence. This kind of liability is called criminal liability.

Changes will be needed concerning criminal liability. In a normal situation the captain will be responsible for the mistakes made onboard of the vessel. If these mistakes are big enough for an imprisonment, the captain will be liable for the mistakes which are made onboard of the vessel. When there will be unmanned vessels sailing the seas and the software of the ship fails, there will be no crew to be held liable for the potential damage made. This will mean that the company or the software programmer will be held liable for the damage made.

When regular vessels are built the ship will have a sea trial where the ship will be tested. When this trial succeeds a big part of the liability of the ship will go from the shipbuilder to the shipping company. With new build unmanned vessels this will be expected to be the same, after the sea trial the liability will be for the shipping company and not the shipbuilder anymore.
What is expected is that the ship will take the criminal liability from the captain. This will be the easiest way to hold someone or something liable since the ship will be the easiest way to hold “hostage”, an amount of money can be asked for the ship. The problem in this situation is that a ship cannot be held liable for an imprisonment, the liability will go to someone else. The vessel is property of the shipping company and the company owner is responsible for the company in most ways. This means that the easiest solution will be that the company owner will be held liable for any imprisonments.

During a collision maritime officers will mostly get a suspension of their maritime license if the effects of the collision are not too big. This kind of punishments cannot be given anymore when a vessel is sailing unmanned. A possible change for such a punishment will be that the suspension of the maritime officer will fall on the vessel which made the accident.

In the first few years of unmanned vessels it will not be possible to sail all the way from A to B unmanned. The harbor track and coastal track will be semi-autonomous. In these phases the criminal liability will be different from the part where the ship is sailing autonomously.

From a shore based station the ships will be controlled and monitored during these tracks. If something happens with the ship during this phase there will be someone responsible for the mistakes, just like a normal crew on board of a manned vessel. The man behind the wheel in this shore based station will be responsible for any mistakes he makes but he won’t be responsible if the software fails.

(Heijboer, 2016)

6.3 Case
A case will be described in this chapter. The case will be worked out in two ways;
- A collision between two manned vessels (The original case).
- A collision between one manned vessel and one unmanned vessel.

The case.
“On 22 August 2014, at around 14.52 hours, in good visibility and calm seas, the Dutch seagoing vessel Arklow Beach collided with the French fishing vessel Elluma in the Bay of Biscay. The Elluma was one of a group of six fishing vessels and was bringing up the rear. These fishing vessels, which were not fishing at the time, approached to port in relation to the Arklow Beach. The courses of the Arklow Beach and the fishing vessels crossed each other. Although the Arklow Beach was not obliged to take evasive action, the person concerned, as second mate on watch on the bridge, changed the course of the Arklow Beach slightly to port, which resulted in a CPA of 0.6 NM with the Elluma as the vessel bringing up the rear of the group of fishing vessels. It can be assumed that this slight change of course was not clearly perceivable to the Elluma. When the first five fishing vessels had crossed in front of the Arklow Beach, the person concerned noticed that the Elluma had reduced speed, as a result of which the CPA quickly reduced, first to 0.2 NM, and following a change of course to starboard made by the Elluma, the distance to the bow of the Arklow Beach was a mere 0.1 NM. The ships then approached each other rapidly on opposing courses. Attempts made on board both vessels to avoid each other by changing course did not have the intended result, and a head-on collision followed. The bows of the Elluma were seriously damaged and one of the two crew members of the Elluma suffered a slight injury. The Arklow Beach sustained slight damage to its bows.”

The decision.
“The Disciplinary Court:
- Declares the objections against the person concerned as stated under point 5 to be well-founded;
- Suspends the navigation license of the person concerned for a period of six (6) weeks;
- Stipulates that of this suspension, a period of four (4) weeks will not be imposed unless the Disciplinary Court stipulates otherwise in a subsequent ruling based on the fact that the person concerned has once again behaved contrary to his duty of care as a good seaman in respect of the people on board, the vessel, its cargo, the environment or shipping prior to the end of a probationary period, which the Disciplinary Court hereby sets at two years;
- Stipulates that the probationary period of the suspension shall commence on the date six weeks following the date of this ruling being forwarded.”

(scheepvaart, 2016)

The case with one unmanned vessel.

In the case described above the Arklow Beach will now be an autonomous vessel, sailing in automatic mode. The Arklow Beach reacted on the small fishing vessels but after the first course change the Arklow beach did not react any further because he was supposed to keep his course and speed like he’s supposed to following the COLREGS.

In a situation like this the Arklow Beach is supposed to adjust her course according to good seamanship but failed to do so because there is no crew onboard.

The fishing vessel did not react according to the COLREGS and will be liable for his mistakes. The decision will not be any different because the unmanned vessel did not act according to rule 8a from part B of the COLREGS. The punishment will still be for the Arklow beach but the punishment which was given was a suspension of the navigational license. The decision for this situation could be a suspension of sailing for the Arklow beach or a bigger financial fine.

6.4 Conclusion

The financial liability with semi-autonomous and autonomous vessel would not change, the liability stays with the shipping company. There will be more financial liability because criminal liability will be much harder to apply on the vessel.

For criminal liability there will be some changes. During any incidents the ship will be held liable, this will come down to the shipping company and the company owner. When the vessel is sailing semi-automatic and is controlled from a shore based station the one in charge of the vessel at that very moment will be held liable for the incidents. But when the software fails and the command center couldn’t do anything about the incident the ship will be liable and there by the company.
The project assignment has been divided in the main question and sub questions. The conclusions of the sub questions together will result in an answer for the main question.

Safety:
A conclusion can be made that a lot of risks exist concerning autonomous sailing. Some changes have to be made to assure a safe navigation for autonomous vessels. Not only technology wise but also the legislation. MUNIN (maritime unmanned navigation through intelligence in network) recently brought out a final report stating as follows:
“Safety and security analysis besides profitability, safety is of course leveraging the implementation of unmanned vessels. The incident categories collision and foundering are responsible for almost 50% of all total losses in the 2005 to 2014 period. Thus it clearly represents the category with the highest incident probability. Furthermore, human errors are a crucial part of the root cause of most maritime accidents. Based on an analysis of collision and foundering scenarios for a MUNIN concept vessel and given a proper operational and robustness testing, a decrease of collision and foundering risk of around ten times compared to manned shipping was found to be possible, mainly due to the elimination of fatigue issues. Also, risks of engine and other system breakdowns are expected to be lower for unmanned ships if proper redundancy is implemented and improved maintenance and monitoring schemes are followed. Fire and explosion represents a relatively small part of all incidents. With the possibility to use more efficient extinguishing systems in fully enclosed spaces, it is likely that the un-manned ship will be much less risk-prone than the manned ship. Finally, risks from cyber-attacks and pirates are issues that cause concern. However, software systems as well as ships can be designed and built providing a very high resilience against digital and physical attacks.”
(Munin, 2015) Munin is one of the biggest organizations that is doing research for unmanned sailing.

All the risks that come with autonomous sailing can be solved. Also the human factor will be removed which cause 75-96% of all collisions and other accidents on sea. Statistically, the autonomous ships can improve global safety by removing the human factor, improving technology on board and adjusting COLREG rules.

If the human factor will be removed from the vessel the safety will improve. AI human errors will no longer be an issue, there will be no human lives at stake during heavy weather or emergency situations. The only con is that there will be no human ability to respond in these situations. “As human beings, we all have certain abilities and limitations. For example, human beings are great at pattern discrimination and recognition. There isn’t a machine in the world that can interpret a radar screen as well as a trained human being can. On the other hand, we are fairly limited in our memory capacity and in our ability to calculate numbers quickly and accurately—machines can do a much better job. In addition to these inborn characteristics, human performance is also influenced by the knowledge and skills we have acquired, as well as by internal regulators such as motivation and alertness.” (Dr. Anita M. Rothblum U.S. Coast Guard Research & Development Center)

To improve safety of navigation in hybrid sailing the COLREGS would need to be adjusted. A separate regulation concerning unmanned vessels would clarify the use of navigation for manned vessels. This means that the unmanned vessel would carry distinctive lighting, day marks and their own rules for avoiding collisions. An unmanned vessel cannot give human assistance to other vessels in danger.

To maintain safety for all at sea, the COLREGS need adjusting when the autonomous vessel will start sailing. One way to do this could be to make an autonomous vessel a different “type” of ship in the regulations. This way the COLREGS will stay the same for all manned vessels. And based on all the research, the autonomous vessel will be safer. This would mean that the COLREGS do not need to be
adjusted for autonomous vessels concerning avoiding collisions. The rules are still applicable with modern day technology, even on autonomous vessels. The only important alteration is to make sure autonomous vessels can be identified. This way manned vessels can consider their actions. This means that the autonomous vessel would get characteristic lighting and daymarks.

**Legislation & Liability:**
To make autonomous sailing comply with legislations, a lot of different regulations have to be adjusted. But, the changes don’t have to be major, probably just adding an amendment to the current regulations. (P&I, 2016)

To make autonomous sailing comply with legislations, a lot of different regulations have to be adjusted. But, the changes don’t have to be major, probably just adding an amendment to the current regulations. (P&I, 2016)

To make autonomous sailing comply with legislation, liability and safety changes are required for the following things:
- Removing the human factor
- Improving technology
- Enhancing new COLREG rules
- many regulations need to be adjusted (see table 1)
- Making clear regulations for criminal liability

**Main question:**
How can the safety, liability and legislation be set up to comply with autonomous sailing?

To make autonomous sailing comply with legislation, liability and safety there needs to be changed the following things.
- Removing the human factor
- Improving technology
- Enhancing new COLREG rules
- A lot of regulation needs to be adjusted (see table 1)
- Criminal liability

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<thead>
<tr>
<th>SOLAS</th>
<th>Chapter IV &amp; V (Regulation 11,14,22,33)</th>
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<tr>
<td>COLREG</td>
<td>Part A &amp; Article 9</td>
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<td>Article 94</td>
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<tr>
<td>ISM CODE</td>
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</tbody>
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*Table 2*
8 Recommendations

Safety
To improve safety at sea when autonomous ships sail, changes in the COLREGS are needed, as well as a solution for communication between vessels. Also the maintenance on board is something that needs to change to avoid propulsion breakdown. Preventive maintenance and system redundancy will decrease the risks of propulsion breakdowns.

An option would be to have all autonomous ships carry white, blue, white lights. The contrast between white and blue can be seen well even during reduced visibility. During the day these ships could show a triangle pointing down, a ball and then a triangle pointing up to clearly state that they are autonomous vessels.

Legislation
To make autonomous vessels comply with legislations, a few changes have to be made. These changes are not major, but every seafarer should be aware of the new regulations. To make these changes in legislation, more research is required.

Liability
Financial liability.
When it comes to financial liability, not many changes will be required. The fees resulting from incidents were usually going to the shipping company, this will not change for autonomous vessels. What will change in the financial part is that there will be more fees with unmanned vessel because criminal liability will not be possible in all situations. These fines will still be for the shipping company.

Criminal liability.
In the criminal liability part there are some recommendations needed. In situations where on manned vessels a maritime license would be suspended, autonomous vessels could have their sailing license suspended instead. Meaning the vessel will not be able to sail for an amount of time.

Another punishment for manned vessel is imprisonment. This is also a punishment which needs to be changed or adapted. Because there is no crew on board autonomous vessels it could become unclear who is liable for this punishment. When an unmanned ship is guilty of an oil spill the ship will be held responsible. In most of the situation the shipping owner or a designated person could be held liable for this punishment.
9 Bibliografie


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10 Appendix I (Group 5 Propulsion and maintenance)

Redundancy factor
Redundancy means that critical systems or components are duplicated with the intention to decrease the affects off a default in the system. In case of an event the backup systems takes over.

Harmonic distortion
Harmonic distortion means that the sinus of the electrical power is not a pure sinus. This will affect the rendement off the electrical system and the lifetime of electrical components. A harmonic distortion can occur by several occasions. In the event of a great prompted electrical power the power supply is slow off reacting this means the pure sinus will be affected. But when the engine has reacted this kind off harmonic distortion is dissolved. There is also a distortion caused by electrical components. These distortions need to be filtered out by power electronics ore by the use of electrical transformers.

Three electrical installations have the specifications to be used in an autonomous vessel. First of all the shaft generator, Secondly Hydrid propulsion (MAN, 2008), and last Low Loss concept (LLC) (wartsila, 2015)

Shaft generator
On traditional merchant vessels the ship is equipped with a shaft generator. This generator is providing the power on sea going trails. As can be seen in figure 1 the shaft generator is supplying the vessel of electrical power. This configuration has proven to be an energy saving solution in the past. That’s also why this set up is relative in expensive. The down side of this configuration is when the power to the ships propeller is fluctuating, this can occur when in heavy weather the propeller is above the water and then submerge again. This fluctuation off the propeller power is affecting the power output of the generator. Fluctuations in the power can be captured by an auxiliary engine. Only the harmonic distortion cannot be filtered out. Harmonic distortion has a negative influence on the life time of electrical components, especially on sensors. When sailing autonomous sensors are a key part of the operations. Also in case of an event with the main engine there is no possibility to deliver power to the propeller by the shaft generator.

![Figure 1](WETech, 2013)
Hybrid propulsion

Hybrid propulsion with PTO/PTI as shown in figure 2 is a better configuration of the traditional shaft generator. In this setup the shaft generator can deliver power to the electrical system but also it can take power to power the propeller. In this setup redundancy is significant higher than in the traditional setup. Even will by use of Power management system (PMS) the fuel consumption be reduced. The disadvantage of this configuration is that when the shaft generator is providing power to the electrical system there will be a harmonic distortion. If the shaft generator only be used in the case of an event the harmonic distortion is not an issue. But when it is only there for the redundancy factor it will be expansive investment.

Low Loss Concept (LLC)

The Low loss Concept (LLC) as shown in Figure 3 patent by Wartsila is a new concept based on the hybrid propulsion concept. Only the configuration is quite different from the hybrid propulsion, by the use of the LLC the need of a transformer for every frequentie drive is not necessary. The LLC concept is based on the 30 degrees phase shifting transformer. The benefits of this configuration are:

- High redundancy
  - Redundancy switchboard has 4 individual parts in case of a worst case single failure power reduced to 75% and al propellers still running
  - Any fault gives minimum operational consequences
  - Reduced power due to less consequences of major faults

- Instant power restoration
- All transformers remain connected during black out, enables instant restart of power supply
- Network disturbances are dampened by the LLC transformers connected in series

- Total harmonic distortion (THD)
  - LLC transformers reduce THD to a max of 5% and approximately 3%

- Safer operation
  - Centralized location of the vital equipment enables easy and secure commissioning, operation, control and maintenance
  - As significantly reduce short circuit level increases personnel safety, also added safety by arc detection device

- Significant savings in space and weight
  - No transformers/converters in propulsion area, more cargo room available
  - Low voltage system allows a more flexible compact switchboard room
  - Less and smaller components saves weight when LV components can be chosen instead of MV components

- Fuel savings
  - Power feed directly from generators to converters saves fuel. Eliminates transformer losses
  - Total electric losses reduced to 5.5-7%. Which is 2-3% lower than competing concepts

- Redundant power generation
  - The power of one generator to be transferred across the LCC transformer enabling optimal and “free” choice of generators to be running

- Increased network stability
  - Transformer impedances reduces the impact of a large failure in the network, such as major voltage disturbances (short circuit on or close to the main bus bar) or frequency oscillations

- Green energy
  - Making use of the sun and wind as power supply
Redundancy

Redundancy for an autonomous vessel is highly important. Because there needs to be always a connection between the shore and the vessel. To get this high redundancy there will be looked at the Environmental Regularity Number (ERN). ‘The ERN number Defining a vessel’s ability to maintain its position Developed in the 1970s by Det Norske Veritas (DNV), the Environmental Regularity Number (ERN, also ern) is a theoretical way of defining a vessel’s ability to maintain its position in different weather and sea conditions. As only lateral forces are involved - wind, waves and current come in on the beam - the calculations involved are relatively simple. The ERN consists of four groups of integers, each of which is stated by DNV to reflect “the probable regularity for keeping position in a defined area”. The format of an ERN is a series of four numbers ranging from 0 to 99. ERNs are stated in shipping registers in the form ern (a, b, c, d), in which a represents the optimal use of all thrusters, b represents the minimum effect of a single-thruster failure, c represents the maximum effect of a single-thruster failure, and d represents the effect of the worst case single failure(s). In a guidance note, DNV says: “The fourth number d shall represent the case where stop of the redundancy group resulting in the largest reduction of position and heading keeping has occurred. (106)” In practical terms, a represents the probability that a vessel will be able to maintain a required position at a certain location in the North Sea when all its systems are fully operational, b indicates the probability that it will be able to maintain its desired position if the least effective thruster fails, c indicates the probability that it will be able to maintain position if the most-effective thruster fails, and d indicates the probability that it will be able to maintain position in the worst-case single failure. The highest possible ERN rating - a score of 99 for a, b, c and d - is 99.99.99.99’ (l, K, & M)

This number is already widely spread in the offshore. This ERN number can now also be used in the autonomous vessel. This because if an vessel can maintain its position is it also possible to maintain the course of the vessel. The redundancy number off the Wartsila low loss concept is 99,99,99,99 this is the highest possible. This means that even when a worst case single failure occurs the ship will have 75% of is power and all off the essential systems still having power.
**Instant power restoration**

If a vessel is sailing autonomous and there is an event of power loss onboard. The restore of the power has than priority to maintain contact with the vessel. With traditional systems the electrical transformers has to be reset. In the Wartsila LLC the electrical transformers does not has to been rest. So only a commando form the shore to start an engine is enough to provide the ship with power. This will speed up the power restore, and there by also the safety of the vessel.

**Total harmonic distortion (THD)**

When a ship is sailing diesel electric the power supply can be “slow” reacting on the sought power. What results in a distortion of the voltage and/or current called harmonic distortion. This THD is affecting the life time of electrical components especially these from the sensors. When THD occurs in the Wartsila Low Loss system the harmonic distortion is filtered out by the transformers, these transformers will damp the THD to max 5% and approximately to 3%.

**Safer operations**

The part of safer operations is not directly an obvious advantage. But when autonomous vessels needs repairs when in the harbor. Specialized crew will work onboard with unfamiliar engine room/technical space. By the use of the Wartsila LLC the voltage can be lower with a higher power output. This is achieved by the use of 2 separate bus bar systems as can be seen in Figure 3. The advantage of this lower voltage is the maintenance of the system. When having a low voltage system the components are cheaper, the maintenance is easier And when arriving in a port and there needs to be worked on the electrical system. Not every port has qualified mechanics to work on a high voltage system.

**Significant saving in space and weight**

Wartsila’s low loss concept is equipped with only two 30 degrees shifting transformers. Compared to current installations where every frequency converter needs an individual transformer for operation and filtering out the THD. This is already a huge saving of weight and space. Nowadays when a ship has a ERN off 99,99,99,99,9 there generators are overpowered to get the highest ERN number. When applying the wartsila LLC the power of the generators can be brought down with 54% this is a significant saving in weight and space. This saving in weight and space will benefit the cargo space and the load that can be carried by the ship.
**Fuel savings**

As mention before when the vessel is equipped with the wartsila low loss concept the power off the engines can be brought down. Nowadays the engines are way to big so they are not running on the optimal load this results in a higher specific fuel consumption and a less effective combustion. There is also another aspect that reduces the fuel consumption. The LLC reduce the electrical losses in the electrical system. This is reached by the use of only 2 transformers and not a transformer for every frequency drive. The fuel saving can be as much as 9%.

**Redundant power generation**

In an full electric ship like wartsila LLC there is a free choice of running engine. For the electrical system it does not matter witch engine is running. This is a great advantage even in the event of an engine failing there can be interrupted by the shore. The loss of this engine will not affect the distribution of the electrical power. This only affects the available power. This loss of power is not affecting the course heading of the vessel this because the vessel has the highest possible ERN number.

**Increased network stability**

As mantioned before by making use of the 30 degrees phase shifting electrical transformers the HTD is reduced to maximal 5% this will increase the stability of your network and there for also the lifetime of electrical components. Even if there will be an short cut in the electrical system or generator the electrical transformer will block this so only one side of the transformer is affected.

**Green energy**

When a ship is full electric the power obtained from solar panels or wind energy can be put directly on the power distribution onboard. When green energy is supplyed the PWS of the vessel will reduce the power of the engines. This will result in an fuel saving and saving of the emission. In the rare event of a black out onboard the solar panels and/or wind energy can provide the critical systems of the vessel of electrical power.
Appendix II (Project group 1: Detection)

Advanced sensor module
If the ship must detect targets the same as the human navigator does, than the most basic method of detecting must be addressed namely the eyes. Using spectral cameras in combination with RADAR and AIS data, the autonomous ship can determine if the target is a danger to the ship or if the target needs to be investigated further. The camera maintains a proper lookout for other ship traffic, obstacles, and needs to be able to identify life rafts, or floating obstacles in the vicinity of the ship that can pose a danger to the navigation. Besides the basic lookout, the camera should also collect and assess meteorological data and sea condition doing so replacing the perceptions of the human navigator. Because the camera can detect a wider spectrum than the human eye can percept, for example infra-red more visual data can be attained to ensure a safe navigation.

There are cameras like a system developed by General Dynamics .Inc. (Dynamics, 2016) that already meet the criteria as described above. One of their more advanced systems claims that it has an integrated 55 times zoom visible camera with cooled infra-red sensor technology that can be applied for autonomic integration.

This camera system contains:

- Cooled 3-5μm Infrared Sensor
- Tri- or Quad-Field-of-View Options
- Integrated 55x Zoom Visible Camera
- Focal Plane Array Choices: 320 x 256, 640 x 512, 640 x 480 (High Reliability Cooler Option)
- Integrated Precision Positioning System
- 2-Axis Gyro-Stabilization (Optional)
- Auto and Manual Focus
- Laser Rangefinder (Optional)

This is an example of a camera system that can be used to replace the human navigator in terms of visual lookout.
Possibilities of drones onboard autonomous vessels for prevention of piracy

The idea
Implementing a drone(s) onboard autonomous vessels to prevent a piracy attack. In case pirates attempt to attack the vessel, the controlling of the drone(s) is given to an anti-piracy centre or could be done by the normal control centre. But controlling drone’s actually a job apart, not mentioned that the situations at sea are not perfect all the time. For this reason, a apart anti-piracy centre would give a solution.

Law regulations of ship security
This whole innovation gives a few problems for instance the legislation for the use of these drones combined with the liability after pirates are injured or killed. Since the navy is using jets to drop bombs in war area’s and the military is using drones to bomb there, as well to kill terrorists, the anti-piracy centre could be controlled by an special part of the military. Still international regulations and agreements have to be agreed between countries. The main objective here is to replace drone’s for the now a days security onboard of manned vessels.

Territorial waters
Under UNCLOS, naval vessels are not permitted to pursue pirates within the territorial waters of a state. However, Resolution 1897, which is accepted under UNCLOS, grants permission to all states to enter the territorial waters of Somalia to suppress piracy and unlawful acts. Such regulation is necessary for implementing drones onboard autonomous vessels to replace security. When discussing these regulations, in mind should be kept, the requirement that the piratical act occur on the high seas or outside the jurisdiction of any state is particularly important. Pirates know international law as well. Acts of maritime violence within territorial waters are not technically acts of piracy under international law. However, maritime violence within territorial waters may constitute piracy under the state’s domestic law. States have exclusive jurisdiction over their own territorial waters and can punish criminal activity within that zone according to UNCLOS supra note 1, art 2. Therefore, a pirate does not violate international law if the piratical activity occurs within the territorial waters of a state. (fedeli, sd)
At sea:

Private security guards who kill unarmed civilians at sea are not likely to be held personally accountable for violations of the Laws of War, as set forth by the Geneva Conventions, for two reasons.

First, piracy does not amount to warfare. Generally, war can only be between states, and pirates are private actors.

Second, private actors are generally not accountable under the Laws of War.

In Prosecutor v. Akayesu, the International Criminal Tribunal for Rwanda stated:  
The duties and responsibilities of the Geneva Conventions and the Additional Protocols...will normally apply only to individuals of all ranks belonging to the armed forces under the military command of either of the belligerent parties, or to individuals who were legitimately mandated and expected, as public officials or agents or persons otherwise holding public authority or de facto representing the Government, to support or fulfill the war efforts. 

Therefore, private security would not be criminally liable for violations of the Laws of War.

(fedeli, sd)

This all says, private security has no regulations, yet, for killing pirates at sea. The regulations at territorial waters depend on the law of the county but still, there are possibilities regarding the regulations for private security now a days, compared to the necessary regulations for drone’s.
Appendix IV (Interview Raets Marine)

Tamara Buijsse

For now the shipping company is liable for the economic damage, and in the nearby future there will be no big change. The expectation is that this will increase, because it will be more difficult to blame a person for the damage.

For example, if there is a collision between 2 ships, 1 autonomic and 1 manned, who will be responsible for the damage?
The responsibility will be with the vessel, and the liability will end with the shipping company. The expectation will be that the fault comes from the software, and the shipping company will try to claim the damage at the software company.

Criminal Liability will shift to Shore based crew / ship owner/ Shipping company.
Economical Liability will shift to the Ship owner, because in this party you can find the most money.
Appendix V (Interview Dutch P&I)

Nils Heijboer

For this moment if a collision occurs there will be determinate who made what mistakes, and which legislations are exceeded. On base of this information there will be determinate who is liable for the costs and damage. In this case one party will never receive 100% guilt. In the future when autonomous sailing is a fact, this needs to be checked again, because there is no crew on board of the autonomous vessel. The expectation is that there will be not so many changes in the financial liability, because still will be looked at who caused the problem and who made mistakes. The only difference is that the ship and shipping company will be responsible finally.

In case a ship is damaged and for example leak oil, there will be investigated who caused the problem, if it is a human factor by crew the master is criminal liable. If de same situation occurs with an autonomous vessel there is no master to keep liable. So who is criminal liable? With semi-autonomous ship the liability will be with control center who is in command of the vessel. If not, it is easy to say that the ship is responsible, the shipping company. For now it is not possible to keep the shipping company liable for a solitary confinement. A possible solution is that the responsible person of the company kept responsible.

Collision by faulty decision of software:
The ship is responsible, so finally the shipping company.

Collision by late warning to shore based crew:
The ship is responsible, so finally the shipping company.

Collision by fault of shore based person:
The shore based person is kept responsible, in some cases the shipping company can kept responsible.

In case there is an error in the software which will result in a collision the shipping company will be held liable because the vessel is property of the shipping company. The shipping company can move the financial cost of the incident to the supplier of the software. This will be arranged in the contracts between the shipping company and the supplier. De supplier will deliver the software on the new build ship, just like with ships nowadays the system will be tested during the sea trial. If the software works during the sea trial and it receives a certificate the liability of the software will go to the shipping company. When the vessel is sailing after the sea trial and the system fails the shipping company will still be able to inform the supplier responsible for the software.
15 Appendix VI
Mr de leeuw

How do we look at this project?
Is autonomous sailing being developed because it is safer?
Or is it being implemented a does it have to be safe enough?

Liability
It is important that there is a distinction between:
- Criminal liability
- Economic liability

Suggestion for the main question
What changes in legislation are required to make autonomous sailing possible, according to safety and liability?

The difference between autonomous vessels and remote controlled vessels is not big.