
# MSc Thesis

## Improve decision making of the crew by optimizing communication between vessels

Ingmar Wever (4161041)

March 19, 2018

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| Student: | Ingmar Wever | 4161041 |
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| | | |
| Supervisors: | Dr. ir. Robert Hekkenberg | TU Delft, Maritime Technology |
| | Prof. Dr. Mark Neerincx | TU Delft, Computer Science |
| | Toine Cleophas | Damen Shipyards |

# Notes

# Preface

# Abstract

# Glossary

## Abbreviations

**AIS** Automatic Identification System, part of VDES

**AMS** Alarm Management System

**CAM-HMI** Central Alert Management Human Machine Interface for presentaiton and handling of alerts

**CFD** Computational Fluid Dynamics

**COLREGs** Convention on the International Regulations for Preventing Collisions at Sea

**DOF** Degrees of freedom

**DP** Dynamic Positioning

**ECDIS** Electronic Chart Display Information System

**ENC** Electronic Navigational Chart

**IEC** International Electrotechnical Commission

**IHO** International Hydrographic Organization

**IMO** International Maritime Organization

**MARPOL** International Convention for the Prevention of Pollution from Ships

**SOLAS** International Convention for the Safety of Life at Sea

**STCW** International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

**TEU** Twenty foot Equivalent Unit

**UID** User Input Device

**VDES** VHF Data Exchange System

**VHF** Very High Frequency radio

# Contents

# 1 | Introduction

Many people are convinced that one of the main developments within the maritime industry will be autonomous shipping. An argument is the improved safety for seafarers, as they don't have to be on board. However this does not necessarily go for all other vessels around the autonomous ship. This is also where one of the main arguments against autonomous shipping come from. How do other (manned) vessels know the intentions of autonomous vessels and can be sure that they will not make unexpected movements?

#### Problem statement

For manned vessels this is currently secured in two ways. First and foremost are the COLREGs, rules applicable to all vessels, as these rules are concrete these can be programmed and used. Examples are to stay on starboard side of the shipping lane and to not cross other ships with small relative angle. However in critical situations such as the entering of harbors or in busy parts of the world, the VHF radio is used to ensure that intentions are clear.

To make autonomous shipping possible, autonomous vessels should know how to communicate their intentions, without overloading the VHF and AIS channels. An optimization of the communication must be done, where others vessels know enough about the intentions to adapt their path to it, without overloading communication channels.

But this is not the same for different vessels, as a long heavy ship will mostly go straight ahead at a similar speed, while a small tug boat might go all over the place. Thereby is there the impact of traffic separation schemes and harbor entrances on the likelihood of manoeuvring in a certain direction.

By adjusting the course in an early stage the intentions can be made clear, making radio communication unnecessary. This will lead to an unimpeded voyage. Beside the advantage of less pressure on the crew, is it also more easy to have autonomous vessels sailing between manned vessels. The moment these intentions have to be communicated is highly dependent on the type of vessel and ship characteristics. During an unimpeded voyage these communications can be avoided as intentions are in all cases clear.

#### Research questions

To enable the step toward autonomous shipping, research will be conducted: When no communication is needed and in case of communication, which information should be shared. This also relates to the different domains of Maritime Technology and Computer Science.

Research question for Maritime Technology:

> *How do ship characteristics influence the time-domain for decision making to ensure an unimpeded voyage?*

Research question for Computer Science:

> *How to optimize the communication between vessels, to support the decision making by the officer of watch?*

#### Thesis structure

Within the project, several steps will be taken. At first more background is given on the current state of the maritime industry, and related developments. Next a more detailed plan of approach for the research is given, including an abstract model on how to improve situational awareness. To test the methodology several scenario's will be used. Therefor these are first defined, leading up to requirements for a tool in which the tests will be performed. These requirements lead to user stories and finally an implementation of a simulation. This simulation is finally validated together with seafarers on the quality of the communication and if ships act realistically within the different scenario's. This is used to give an advice on how to optimize communication. Or more specifically which information should be shared.

# Part I

# The maritime industry

# 2 | Current situation

Safety at sea has been a relevant topic as long as ships exist. And although the shipping industry exists for a long time, communication is where still major steps are taken to improve this safety.

Before the invention of radio communication, ships literally lost all connection with the shore and other ships when setting sail. Using flags some communication was possible when ships were close to each-other or to shore, but this only gave limited insight in the intentions of other vessels.

In the last centuries much have changed, mostly reactive on accidents which occurred. A key event was the disaster with the TITANIC on 15th April 1912, which leaded to the international treaty International Convention for the Safety of Life at Sea (SOLAS). Despite new rules, accidents still occur. Some of them will be discussed below. Followed by a description of the means for communication, equipment used at the bridge and finally whom is using it in what way.

## 2.1 Accidents

Below three accidents are discussed, showing the importance of proper communication to improve situational awareness. The accidents which will be discussed are:

- Collision between MV AL ORAIQ and MV FLINTERSTAR
- Collision between USS FITZGERALD and MV ACX CRYSTAL
- Collision between USS JOHN S MCCAIN and MV ALNIC MC

### 2.1.1 MV AL ORAIQ and MV FLINTERSTAR

During the night between 5 and 6 October 2015 on the Northsea near Zeebrugge, a collision occurred between the LNG tanker AL ORAIQ, sailing under the Marshall Islands flag, and the FLINTERSTAR cargo ship, sailing under the Dutch flag. The FLINTERSTAR sank almost immediately as a result of the collision, an illustration of the accident is shown in Figure 2.1. The captain of the FLINTERSTAR was badly injured in the incident but the other ten people on board and the pilot were rescued out of the water unharmed.

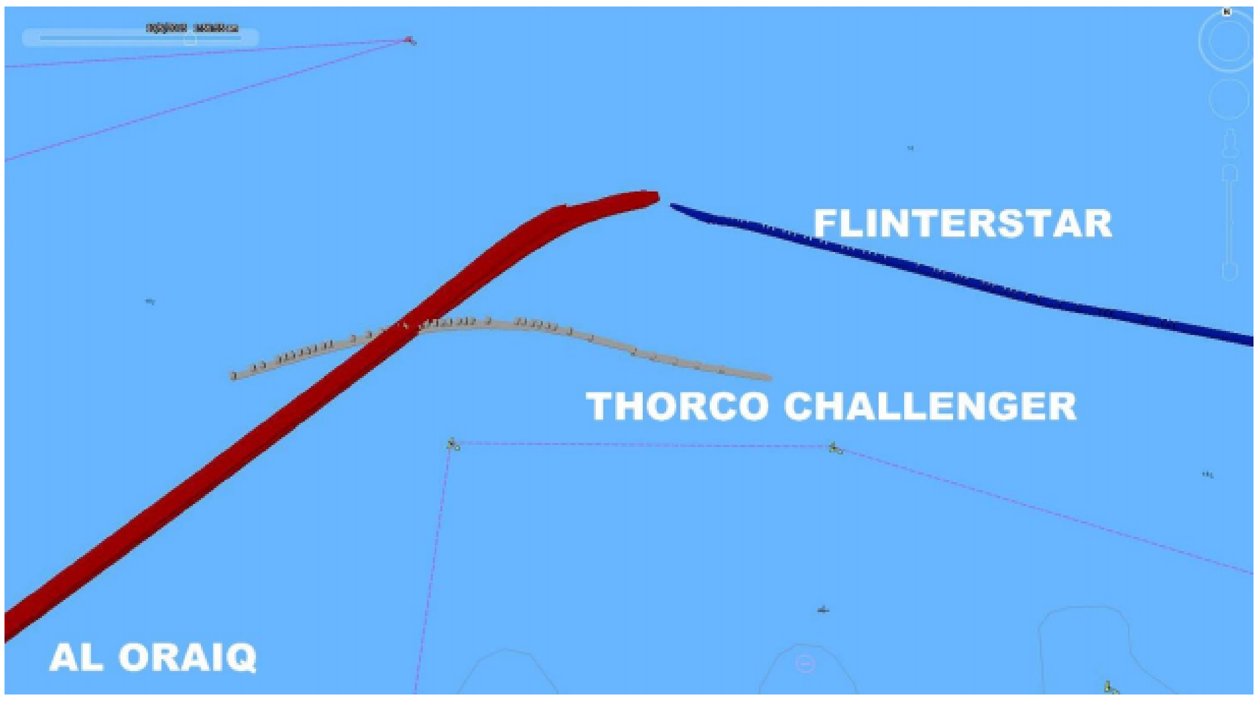


Figure 2.1: Illutstration map of approximate collision location

The collision occurred because the bridge team on board of the AL ORAIQ wrongly assessed the traffic situation, vessel's speed and distance from the S3 buoy, prior to contacting the nearby vessel Thorco Challenger. After informing the Thorco Challenger, did they pass on the starboard side. On board of AL ORAIQ were coastal pilots which did not receive feedback from the watch keepers, nor was there feedback from other vessels via Very High Frequency radio (VHF) radio. The communication which went via VHF radio was mostly in dutch, the officer on duty at AL ORAIQ did not request the Coastal pilots to translate. Also did the bridge watch team not assess the situation properly, leading to very little situational awareness. On board of the FLINTERSTAR there was insufficient attention for watch keeping duties. As several VHF radio communications between Traffic Centre Zeebrugge and other participants within the area monitored by Traffic Centre Zeebrugge, concerning or involving the presence of an inbound LNG carrier were missed by the Pilot and other crew at the bridge on board the FLINTERSTAR. The pilots on board of AL ORAIQ did not attempt to work together. Thereby making decisions without consulting the crew, such as overtaking other vessels. Thus the coastal pilot did not act consistently with international understanding, where a pilot is an advisor to the ship's master. Which means mutual understanding for the functions and duties of each other, based upon effective communication and information exchange. The sea pilot on board of the FLINTERSTAR got engaged in a casual conversation with the officer of the watch, drawing his attention away from monitoring the traffic situation. The Sea Pilot was advising the officer of the watch from what appeared to be routine. [Backer(2015)]

### 2.1.2 USS FITZGERALD and MV ACX CRYSTAL

A more recent well-known collision was between the USS FITZGERALD and ACX CRYSTAL on 17th June 2017. The US destroyer hit the larger Philippines container vessel resulting in the death of 7 US Sailors. An illustration of the accident is shown in figure 2.2. According to the accident report did failures occurred on the part of leadership and watch-standers. There were failures in planning for safety, adhere basic navigational practice, execute basic watchstanding practice, proper use of available navigation tools and wrong responses.

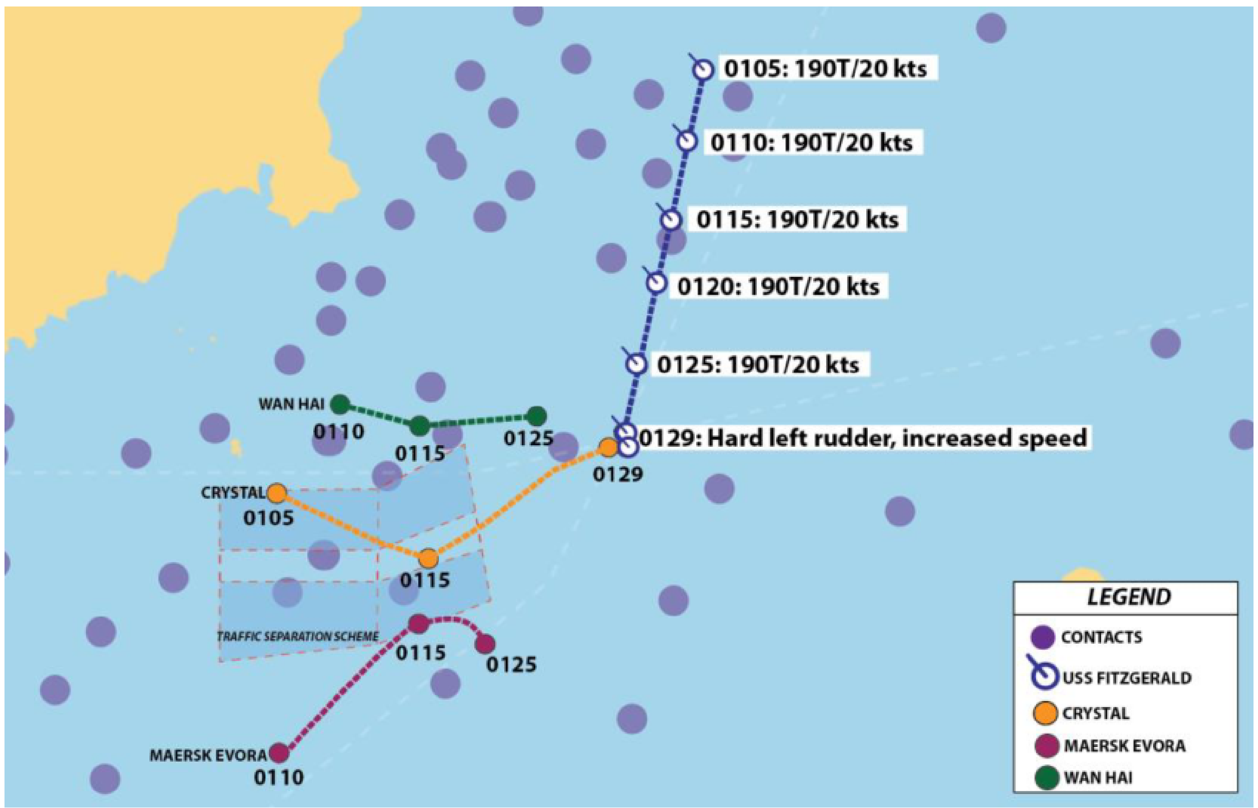


Figure 2.2: Illutstration map of approximate collision location

In accordance with international rules, the USS FITZGERALD was obligated to manoeuvrer to remain clear from the other crossing ships. The officer of the deck responsible for navigation and other crew discussed whether to take action but choose not to, till it was too late. While other crew members also failed to provide more situational awareness and input to the officer of the deck. Did the officer of the deck, exhibit poor seamanship by failing to manoeuvrer as required, failing to sound the danger signal and failing to attempt to contact CRYSTAL on Bridge to Bridge radio. In addition, the Officer of the Deck did not call the Commanding Officer as appropriate and prescribed by Navy procedures to allow him to exercise more senior oversight and judgment of the situation. This was prescribed to an unsatisfactory level of knowledge of the international rules of the nautical road by USS FITZGERALD officers. Thereby were watch team members not familiar with basic radar fundamentals, impeding effective use. Thereby were key supervisors not aware of existing traffic separation schemes and the expected flow of traffic, as the approved navigation track did not account, nor follow the Vessel Traffic Separation Scheme. Secondary was the automated identification system not used properly. [US Navy(2017)]

### 2.1.3 USS JOHN S MCCAIN and MV ALNIC MC

Even more recent is the collision between the USS JOHN S MCCAIN and ALNIC MC on 21st August 2017. The US Destroyer hit the Liberia flagged oil and chemical tanker. Resulting in the death of 10 US Sailors. An illustration of the accident is shown in figure 2.3. According to the accident report did the US Navy identify the following causes for the collision: Loss of situational awareness in response to mistakes in the operation of the USS JOHN S MCCAIN's steering and propulsion system, while in the presence of a high density of maritime traffic. Failure to follow the international nautical rules of the road, which govern the manoeuvring of vessels when risk of collision is present. Watchstanders operating the JOHN S MCCAIN's steering and propulsion systems had insufficient proficiency and knowledge of the system.

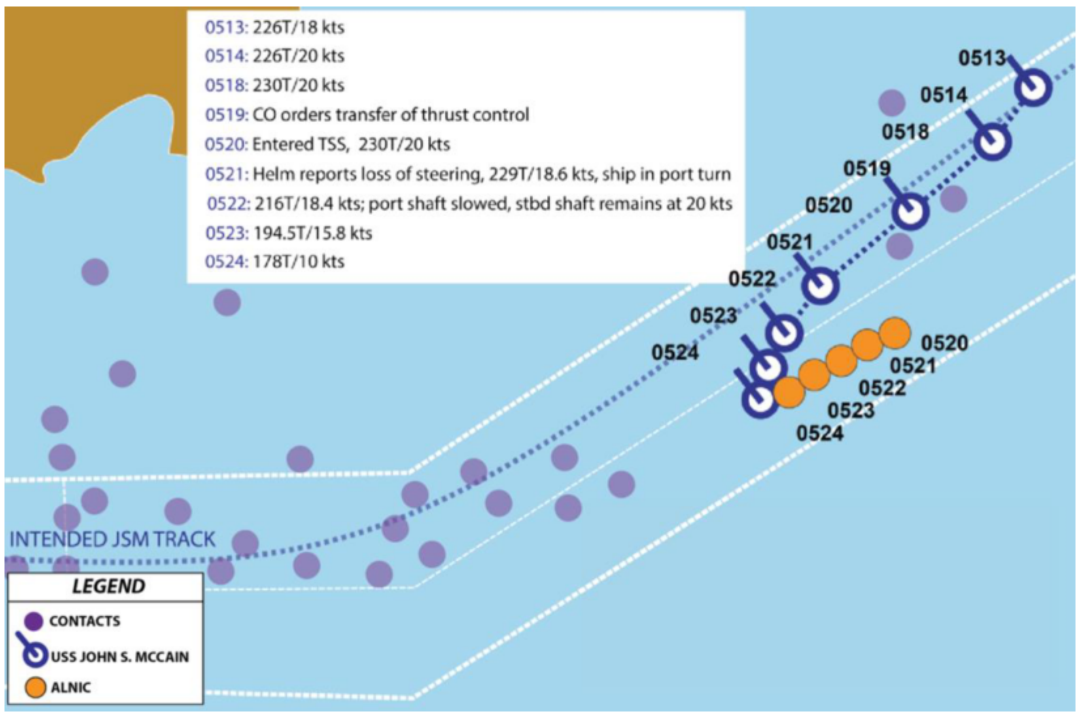


Figure 2.3: Illutstration map of approximate collision location

Leading up to the accident did the commanding officer notice that the helmsman had difficulties maintaining course, while also adjusting the throttles for speed control. In response, he ordered the watch team to divide the duties of steering and throttles, maintaining course control with the Helmsman while shifting speed control to another watchstander. This unplanned shift caused confusion within the watch team, which led to wrong transfers of control, where the crew was not aware of. Watchstanders failed to recognize this configuration. The steering control transfer caused the rudder to go amidships (centerline). Since the Helmsman had been steering less than 4 degrees of right rudder to maintain course before the transfer, the amidships rudder deviated the ship's course to the left. Additionally, when the Helmsman reported a loss of steering, the Commanding Officer slowed the ship to 10 knots and eventually to 5 knots. Due to the wrong transfer did only one shaft slow down, causing an un-commanded turn to the left (port). The commanding officer and others on the ship's bridge lost situational awareness. They did not understand the forces acting on the ship, nor did the understand the ALNIC's course and speed relative to USS JOHN S MCCAIN. Three minutes after the reported loss of steering, was it regained, but already too late to avoid a collision. No signals of warning were send by neither ship, which are required by international rules of the nautical road. Nor was there an attempt to make contact through the VHF bridge-to-bridge communication. Many of the decisions made that led to the accident were the result of poor judgment and decision making of the commanding officer. That said, no single person bears full responsibility for this incident. The crew was unprepared for the situation in which they found themselves through a lack of preparation, ineffective command and control. Deficiencies in training and preparations for navigation were at the base of this. [US Navy(2017)]

## 2.2 Means of communication

Communication is a very broad concept and comes in many forms, as it includes everything which enables the exchange of information. The main reason to communicate is improve the safety of life at sea. More specifically to show intentions or ask for aid. The main means of communication are nowadays:

- Visible signals
  - Change of heading
  - Light signals
  - Flags or symbols
- Availability on VHF
- Exchange of information via Automatic Identification System, part of VDES (AIS)
- Horn

it this the complete list?

## 2.3 The bridge

The bridge of a vessel can be separated into four elements. The human operator, procedures, technical system and the human-machine interface. This chapter will focus on the technical system and human-machine interface. Thereby a separation will be made between the instruments available, the information which can be deducted from this and how this can be used.

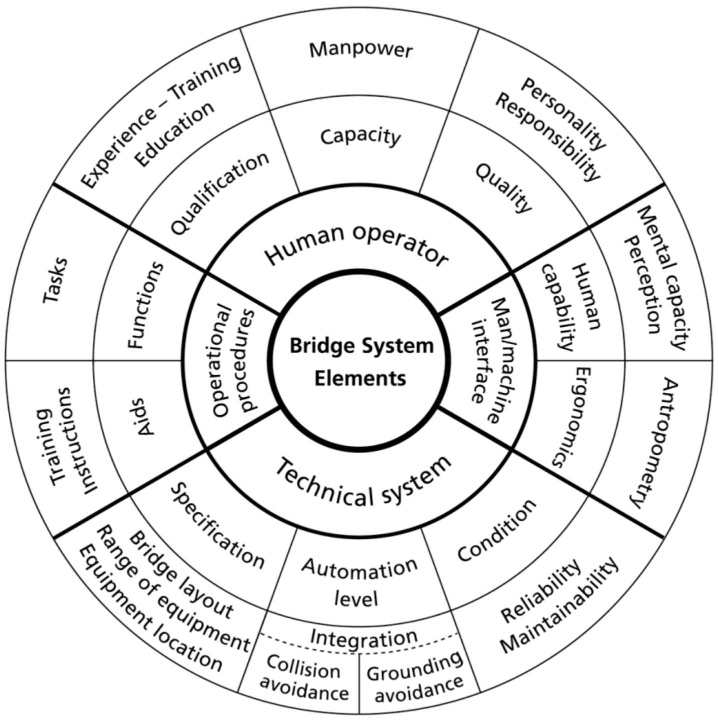


Figure 2.4: Bridge system elements

The ship's navigation bridge shall enable the officer in charge of the navigational watch to perform navigational duties unassisted at all times during normal operating conditions. He shall be able to maintain a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make full appraisal of the situation and the risk of collision, grounding and other hazards to navigation.

### 2.3.1 Technical system

At least the following instruments and equipment shall be installed [DNV GL(2011)]:

- Navigation radar with radar
- Propulsion control
- Manual steering device
- Heading control
- Other related User Input Device (UID)s
- Electronic Chart Display Information System (ECDIS)
- Steering mode selector switch
- VHF unit
- Whistle and manoeuvring light push buttons
- Internal communication equipment
- Central alert management system
- General alarm control
- Window wiper and wash controls
- Control of dimmers for indicators and displays
- Propulsion
- Emergency stop machinery
- Gyrocompass selector switch
- Steering gear pumps

What do regulations say about systems which should be on board

### 2.3.2 Man/machine interface

How is information used

### 2.3.3 Procedures

Training, education and protocols

### 2.3.4 Human operator

How does it go in practice, experience.

# 3 | Future of shipping

The shipping industry is traditionally driven by regulations and making profit, with small margins this does lead to a conservative industry. Many CEO's say digitalization and de-carbonization are watchwords for the coming decade. Projects around this should be leading to a safer shipping industry, which becomes more efficient and at the same time reducing its environmental footprint [Eriksen(2017)]. This research will mainly focus on improving safety at sea, the digitalization is most relevant here, certainly when it comes to autonomous ships. A description will be given of the steps which will most likely be taken in the coming years, which projects are working on the steps towards the future.

Focussing on the digitalization, ships will become more sophisticated. More data is generated by sensors, improved connectivity and new ways to visual data. This enables ships to continuously communicate with managers and traffic controllers. At first, this can be used to analyze data and give better advice based on expected weather, fuel consumption and arrivals at bottlenecks like ports and bridges. This might result in unmanned vessels. Either remotely operated from shore, on autopilot or completely autonomous, as shown in figure 3.1. The different projects around the world follow this same path. Below some of these projects are mentioned with their current status.

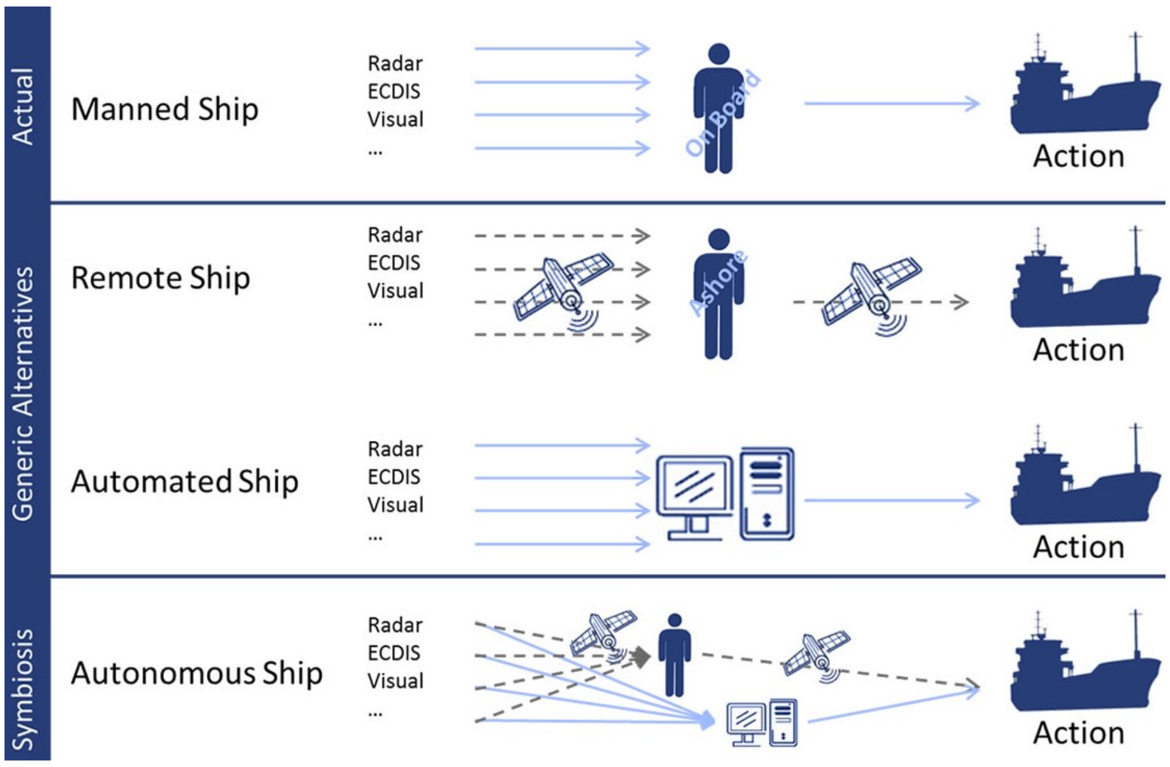


Figure 3.1: From manned to autonomous ships

## 3.1 Projects

The research project MUNIN consists of a consortium of shipbuilders and scientists. The name is an abbreviation for Maritime Unmanned Navigation through Intelligence in Networks and originated from WATERBORNE, an initiative from the EU and Maritime Industries Forum, supporting cooperation and exchange of knowledge between stakeholders within the deep and short sea shipping industry. They did an initial research. Focussing on different elements of an autonomous concept: The development of an IT architecture. Analysis tasks performed on today's bridge and how this will be on an autonomous bridge. Examine the tasks in relation to a vessel's technical system and develop a concept for autonomous operation of the engine room. Define the processes in a shoreside operation center, required to enable a remote control of the vessel. Thereby taking into account the feasibility of the developed solution, including legal and liability barriers for unmanned vessels. They concluded that unmanned vessels can contribute to the aim of a more sustainable maritime transport industry. Especially in Europe, shipping companies have to deal with a demographic change within a highly competitive industry, while at the same time the rising ecological awareness exerts additional pressure on them. The autonomous ship represents a long-term, but comprehensive solution to meet these challenges, as it bears the potential to: Reduce operational expenses and environmental impact. A concept was developed for a bulker vessel, enabling the consortium to do a financial analysis. Showing the viability, but admitting the limited scope of the project [MUNIN(2016)].

### 3.1.1 Visionary projects

Rolls-Royce Marine is involved in different projects which are in some way follow-ups on the MUNIN project. Well-known are the videos of the virtual bridge concept and the Electric Blue, as this was a first clearly drawn vision of how the shipping industry could look like in the future. Electric Blue is a concept ship, based on a standard 1000 Twenty foot Equivalent Unit (TEU) feeder. The ship is very adaptable, it can sail for example on both diesel and electricity. The modularity enables Electric Blue to adapt for specific routes and meet environmental requirements now, and in the future. Keeping in mind the way towards autonomous, will it start with a virtual bridge, housed below the containers. Utilizing the opportunities of sensors for safe navigation, employing radar, camera, IR camera, lidar and AIS. The roadmap for this concept is to have partial autonomy by 2020, remote operation between 2025 and 2030, starting with a reduced passive crew on board. And be fully autonomous in 2035 [Wilson(2017)]. To make these steps they were aware from the start on, that the control room is the nerve center of remote operations. Using an interactive environment with a screen for decision support and improving situation awareness with augmented reality. With these developments does their vision look very promising. However there have not yet been successful prototypes.

- DIMECC/ One Sea - AAWA - ReVolt

infographic with planning for autonomous per project and possibly budgets

### 3.1.2 Industry projects

The Yara Birkeland is one of the projects ahead of the pack, already building and testing a 120 TEU container ship. This vessel will initially operate as fully electric manned vessel, but plans are that it will sail autonomously in 2020. Operating between different Yara facilities in Norway, transporting fertilizers and raw materials. Kongsberg is responsible for the development and delivery of all key enabling technologies. Including the sensors and integration required for remote and autonomous operations, in addition to the electric drive, battery and propulsion control systems [Sames(2017)].

Other smaller projects are the development of Norwegian ferries, which are likely to start sailing automated from 2018, just like an automated shuttle service for offshore installations. The Roboat, a fleet of small pontoons which can be used to solve problems on urban waterways. Such as transportation of people and goods or creating temporary dynamic floating structures like bridges and stages. Which is a collaboration between AMS Institute and MIT.

Since June 2017 is Rolls-Royce also involved in the unmanned cargo ship development alliance, which is initiated by Asian companies and classification bureaus.

Where most of the previous projects were focussed around developing a vessel which has to operate in the current environment. Does the smart shipping challenge focus on combining technological developments within different parts of the inland shipping industry. This will help to steer ships remotely, smarter sharing of information and optimization of waterway maintenance. Good examples are the new vessels from Nedcargo, the Gouwenaar 2 and 3. These vessels will be able to transport more containers, while reducing the fuel consumption. This will not only be acquired by improving the hull shape and machinery, but also by sailing smarter. For example by optimizing the speed, based on opening times for bridges and availability of the quay [SMASH(2017)].

## 3.2 Other stakeholders

State of lloyds and IMO, developing codes for autonomy level and certification of unmanned vessels.

update with info from IRY-OON

## 3.3 TEMPORARY: Roadmaps for different projects

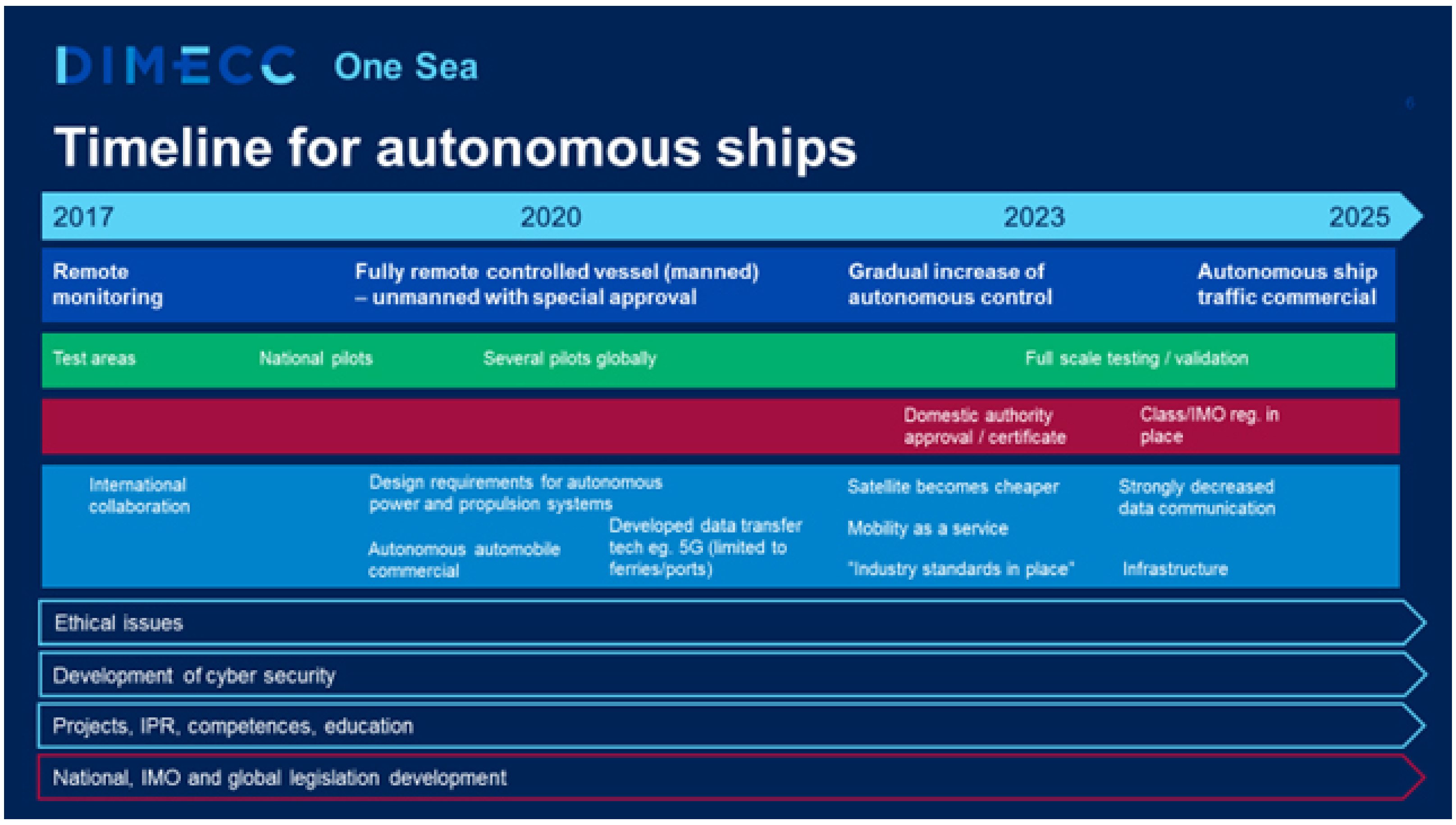


Figure 3.2: Timeline for autonomous ships by DIMECC

## 3.4 Possible use cases

- Tugs as extra actuator in DP-like system - Local transport between factories, terminals, etc. - Crude oil tankers which are traded while at sea - Short sea shipping (most pilots)

## 3.5 Changes in communication

e.g: VDES

## 3.6 Challenges when combining unmanned and manned vessel

# Part II

# Research

# 4 | Steps to be taken

The plans mentioned in section 3 do all have similar challenges which must be solved before autonomous vessels will set sail. One of these issues is related to the current problem already existing within the maritime industry. Situational awareness of the crew. This means getting the right information, understanding the information and making the right decision based on this. In case of navigation this often means understanding the intentions of other ships by sharing the right information.

## 4.1 Specific step on roadmap towards autonomous

Even before the step where manned and unmanned vessels sail together. It is already important to develop a model which can predict the behaviour of other vessels. As this can be used to improved the warning system within current ECDIS systems.

## 4.2 Research questions

The research will be done from two different viewpoints. Where the Maritime part will focus on ship characteristics and how with the right navigational strategy radio communication can be avoided. The part for computer science will focus explicitly on this communication. More specifically which information must be shared to improve situational awareness.

### 4.2.1 Maritime Technology

Critical situations are moments during a voyage where it is most important that is known what the intentions are of other vessels. But due to the chaotic situation this is not always possible. Supporting the crew in showing possible intentions of other vessels will help to create situational awareness faster.

But this is not the same for different vessels, as a long heavy ship will mostly go straight ahead at a similar speed, while a small tug boat might go all over the place. Thereby is there the impact of traffic separation schemes and harbor entrances on the likelihood of manoeuvring in a certain direction. By adjusting the course in an early stage the intentions can be made clear, without the need for communication. This will lead to an unimpeded voyage. Beside the advantage of less pressure on the crew, is it also more easy to have autonomous vessels sailing between manned vessels. The moment these intentions have to communicated is highly dependent on the type of vessel or ship characteristics. During an unimpeded voyage it is not needed to communicate as intentions are in all cases clear. This has led to the following research question:

> *"How do ship characteristics influence the time-domain for decision making to ensure an unimpeded voyage?"*

### 4.2.2 Computer Science

Many people are convinced one of the main developments within the maritime industry will be autonomous shipping. An argument is the improved safety for seafarers, as they don't have to be on board. However this does not necessarily go for all other vessels around the autonomous ship. This is also where one of the main arguments against autonomous shipping come from. How do other (manned) vessels know the intentions of autonomous vessels and can be sure that they will not make unexpected movements?

Currently this is secured in two ways. First and foremost are the COLREGs, rules applicable to all vessels, as these rules are concrete these can be programmed and used. Examples are to stay on starboard side of the shipping lane and to not cross other ships with small relative angle. However in critical situations such as the entering of harbors or in busy parts of the world, the VHF radio is used to ensure that intentions are clear.

To make autonomous shipping possible, autonomous vessels should know how to communicate their intentions, without overloading the VHF and AIS channels. An optimization of the communication must be done, where others vessels know enough about the intentions to adapt their path to it, without overloading communication channels. This leads to the following research question:

> *"How to optimize the communication between vessels, to support the decision making by the officer of watch?"*

## 4.3 Methodology

The first step is to get insight into current solutions and projects related to improving situational awareness within the future. Many of these projects are also steps towards autonomous or unmanned sailing. Based on this, a philosophy can be developed on how to predict the behavior and intentions of other vessels. This leads to a high level abstract model which will be the basis to get insight in the information relevant to develop an implementation of a tool. This tool will initially be used to simulate the behavior, thereby validating if predefined strategies are also logical choices to avoid critical situations in specific scenario's. The scenario's and strategies will eventually be validated together with seafarers.

# 5 | Abstract model

As mentioned first an philosophy is developed on how to improve situational awareness by predicting the behavior. This is written down using an abstract model. Here is also a separation made between the Maritime Technology and Computer Science researches. The reason to make this model is to a clear list of topics relevant to the strategy which will be developed for the specific scenario's. In figure 5.1 a visual of the abstract model is shown. In the next section differents parts of the model will be discussed in more detail.

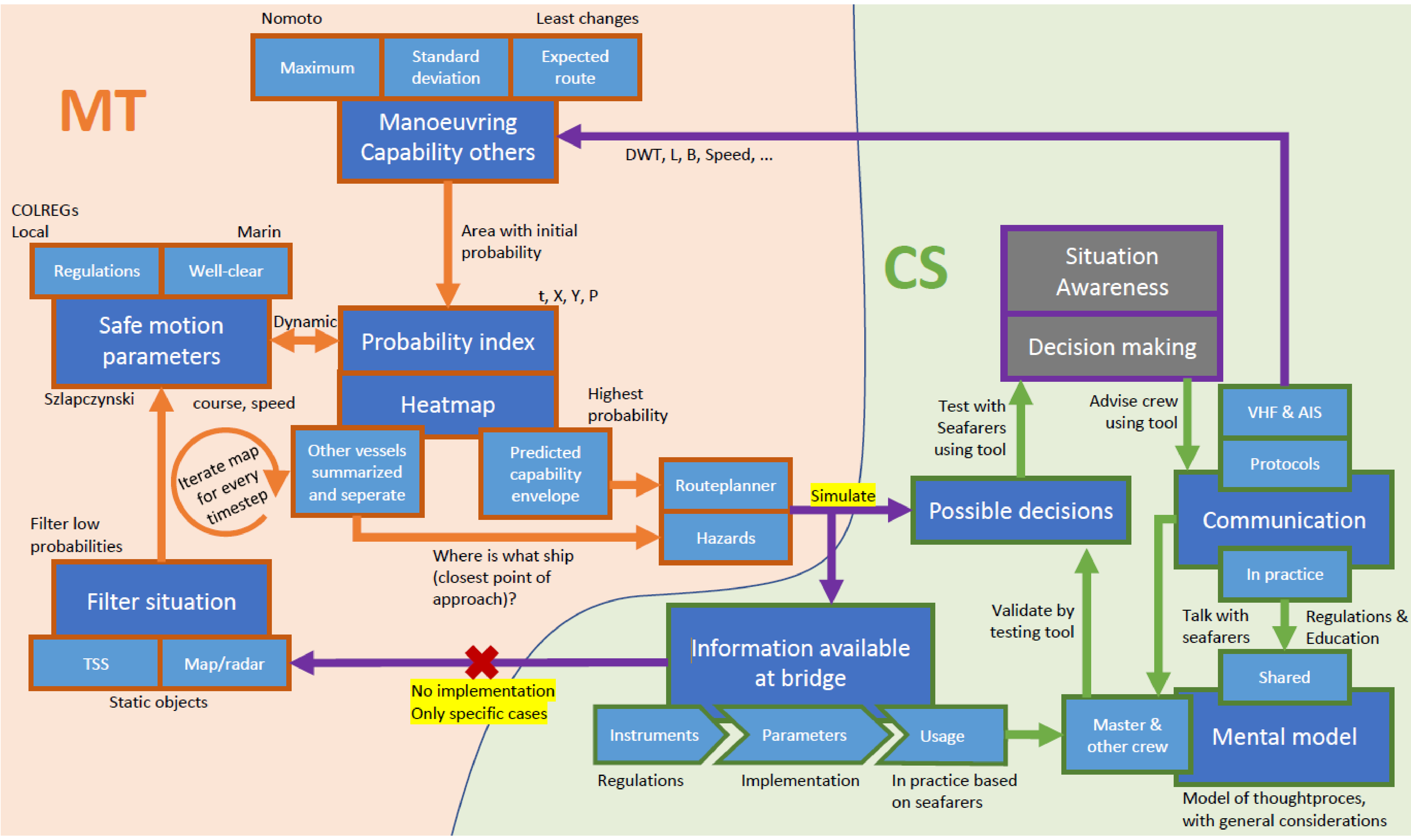


Figure 5.1: Abstract model

## 5.1 Ship characteristics

The main block manoeuvring capability depends on the ship characteristics. Where there is an influence on both feeling of safety, and the physical limitations. For example a ship crossing another vessel could keep sailing straight as long as possible and than make a hard turn, but it rather changes its course earlier in a way where less loss of speed occurs. With a small ship these hard turns are easy and fairly predictable, but t

Therefore the capability of the ship is split up in three categories, expected location, likely change of course done comfortably and physically possible route based on physics laws. As a full CFD simulation is hard to do for every ship which is encountered, models will be used to make estimations quickly. Thereby is important to notice that a high accuracy is not necessary, as those extreme movements have a very low probability to occur. Being a bit conservative here will help to allow for all different scenario's to be tested.

## 5.2 Influencing factors

The same goes for the safe motion parameters. There are regulations on minimal passing distances and how close you should come to others. But good seamanship would be to make intentions clear earlier, so that critical situations can be avoided. The regulations which apply depend on the ship characteristics, just as with the natural laws, the probability of getting to the extreme situations where regulations are followed but still problems might occur are not likely. The model from Szlapczynski is used to set the estimate safety domains for each ship. Leading to courses and speeds which are safe to sail [Szlapczynski and Szlapczynska(2017]. While also incorporating Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) and arbitrary distances for well-clear, which is the distance where everyone feels safe. The COLREGs are also relevant in areas around ports, where traffic separation schemes are used. These should be followed by different types of vessels. This will influence the most likely position for a vessel to be. Incorporating information from traffic controllers will thereby lead to the most likely expected route. The same goes for areas with multiple objects on the map, where ship should navigate around buoys, quays, fishing area's, no-go zones, etc. Combining this with ship characteristics will lead to a map where for each vessels is shown what the probability is it will be at a specific place. When looked at the highest probability this will show the most likely route. When looking at all places with a probability above a specific threshold the possible decision can be defined.

## 5.3 Information and communication

Already mentioned is the impact of other vessels and objects on the probability a ship will be at a specific location. But to know this impact the information has to be gathered from different parameters. Thereby should be looked if the current parameters are sufficient, or if others equipment or instruments should be installed. As currently vision and radio communication are very important ways to gather information. These types of information are difficult to gather using computers. Therefore will the focus be in this research on what information is needed, not how it is gathered. Although developments within technologies to gather this information will be taken into account to eventually develop the strategies. For example related to AIS, VHF Data Exchange System (VDES) and different protocols.

## 5.4 Situational awareness

When combining information, communication, characteristics and possible decisions an image of the situation can be formed. This will be interpreted in a way which enables the right decision making for route-planning. This planned route can be used on autonomous vessels, or be used to advise the crew which decision they should make and what information they should share with others. Mental models will be used to validate if indeed the different vessel have the right information and if enough information is shared. The results from these blocks will be verified with seafarers to validate that the theory corresponds with operations.

# 6 | Scenario's

## 6.1 criteria

- Acceptable distance or well-clear including closest point of approach calculation - Hazards - COLREGs criteria [filters]

## 6.2 situations

## 6.3 Mental model

onthologie

### 6.3.1 Thought process

### 6.3.2 Major differences

equipment, flagstate, origin of crew, etc.

# Part III

# Simulation

# 7 | Requirements

## 7.1 Probability index

what should the polygons show

## 7.2 User stories full application

## 7.3 User stories modules

## 7.4 Assumptions

# 8 | Building and verification

## 8.1 Model and classes

## 8.2 Methods

## 8.3 Estimation of characteristics

Deadweight to displacement for example

## 8.4 Manoeuvring capability model

## 8.5 Routeplanner

Including the usage of waypoints with weights

# 9 | Implementation of scenario's

Testing of the scenario's from research chapter

# Part IV

# Reality

# 10 | Validation of strategies

# 11 | Validation of communication

together with seafarers

## 11.1 Clear intentions

## 11.2 Risk of information overload

## 11.3 Desired input

Do they want this information at the momtent

# 12 | Optimization of communication

what is needed to improve the knowledge on intentions

## 12.1 Safe motion parameters

# Part V

# Wrap-up

# 13 | Results

Describe results when both researches are combined. Do they support each other.

# 14 | Conclusion

## 14.1 Answers to research questions

## 14.2 Recommendations for future research

# Part VI

# TEMPORARY: Old text

# Introduction

Critical situations are moments during a voyage where it is most important that is known what the intentions are of other vessels. But due to the chaotic situation this is not always possible. Supporting the crew in showing possible intentions of other vessels will help to create situational awareness faster.

But this is not the same for different vessels, as a long heavy ship will mostly go straight ahead at a similar speed, while a small tug boat might go all over the place. Thereby is there the impact of traffic separation schemes and harbor entrances on the likelihood of manoeuvring in a certain direction. By adjusting the course in an early stage the intentions can be made clear, without the need for communication. This will lead to an unimpeded voyage. Beside the advantage of less pressure on the crew, is it also more easy to have autonomous vessels sailing between manned vessels. The moment these intentions have to communicated is highly dependent on the type of vessel or ship characteristics. During an unimpeded voyage it is not needed to communicate as intentions are in all cases clear. This has led to the following research question:

*How do ship characteristics influence the time-domain for decision making to ensure an unimpeded voyage?*

The method used within this research is to create a simulation for different situations, showing a visualization of the possible decisions. Extending this with experience from seafarers to improve the interpretation of the tool. To eventually succeed in predicting when the crew has to act to secure an unimpeded voyage.

Question: How do ship characteristics influence the time-domain for decision making to ensure an unimpeded voyage?

ship characteristics:?

Unimpeded voyage: a voyage where is it possible to correctly predict the intentions of other vessels and adapt to this in a timely manner in such a way that the COLREGs are sufficient for route planning.

Hypothesis:

# Introduction

Many people are convinced one of the main developments within the maritime industry will be autonomous shipping. An argument is the improved safety for seafarers, as they don't have to be on board. However this does not necessarily go for all other vessels around the autonomous ship. This is also where one of the main arguments against autonomous shipping come from. How do other (manned) vessels know the intentions of autonomous vessels and can be sure that they will not make unexpected movements?

Currently this is secured in two ways. First and foremost are the COLREGs, rules applicable to all vessels, as these rules are concrete these can be programmed and used. Examples are to stay on starboard side of the shipping lane and to not cross other ships with small relative angle. However in critical situations such as the entering of harbors or in busy parts of the world, the VHF radio is used to ensure that intentions are clear.

To make autonomous shipping possible, autonomous vessels should know how to communicate their intentions, without overloading the VHF and AIS channels. An optimization of the communication must be done, where others vessels know enough about the intentions to adapt their path to it, without overloading communication channels. This leads to the following research question:

> *How to optimize the communication between vessels, using an intelligent agent to support the decision making by the officer of watch?*

The method used within this research is to build a multi-agent system. Where other vessels are seen as semi-intelligent agents. While the own vessel has two agents: A human operator (officer of watch) and an intelligent support system.

# Manoeuvring capability

Ship manoeuvring is the ability to keep course, change course, keep track and change speed. Minimal requirements are given by International Maritime Organization (IMO) standard. However, shipowners may introduce additional requirements. Ship manoeuvrability is described by the following characteristics:

- Initial turning ability (start turning)
- Sustained turning ability (keep turning)
- Yaw checking ability (stop turning motion)
- Stopping ability (in rather short distance and time)
- Yaw stability (ability to move straight ahead)

During sea-trials these capabilities can be determined. However this project will aim at predicting manoeuvrability while using limited input. Thereby is there a difference between the maximum limits and what a ship is likely to do. This will eventually lead to the possible movements of the vessel.

## IMO standard

The manoeuvrability of a ship is considered satisfactory is the following criteria are complied:

1. *Turning ability*. The advance should not exceed 4.5 ship lengths (L) and the tactical diameter should not exceed 5 ship lengths in the turning circle manoeuvre.
2. *Initial turning ability*. With the application of 10°rudder angle to port or starboard, the ship should not have traveled more than 2.5 ship lengths by the time the heading has changed by 10°from the original heading.
3. *Yaw-checking and course-keeping abilities*.
   (a) The value of the first overshoot angle in the 10°/10°zig-zag test should not exceed:
      i. 10°if L/V is less than 10 seconds
      ii. 20°if L/V is 30 seconds or more
      iii. (5 + 1/2(L/V)) degrees if L/V is between 10 and 30 seconds

      where L and V are expressed in m and m/s, respectively.
   (b) The value of the second overshoot angle in the 10°/10°zig-zag test should not exceed:
      i. 25°if L/V is less than 10 seconds
      ii. 40°if L/V is 30 seconds or more
      iii. (117.5 + 0.75(L/V)) degrees if L/V is between 10 and 30 seconds
   (c) The value of the first overshoot angle in the 20°/20°zig-zag test should not exceed 25°.
4. *Stopping ability*. The track reach in the full astern stopping test should not exceed 15 ship lengths. However, this value may be modified by the Administration where ships of large displacement make this criterion impracticable, but should in no case exceed 20 ship lengths.

## Limits

These standards give guidance during seatrials, but won't help much What are maximum values for manoeuvring capability. Based on trial run are values found for Nomoto (other theories?)

Wat is constant? Versnelling/vertraging of de afgeleide daarvan

Clarke, D., Gedling, P. and Hine, G. (1983). The application of manoeuvring criteria in hull design using linear theory. The Naval Architect, pp. 45–68

## Desired capability

What are normal movements for a ship of a specific size

## Expected route

Ship will most likely keep sailing straight and on same speed

describe formula to determine crossing-point of line

## Input

Nomoto, more detailed is Norrbin equation

CPA calculation

### Detailed capability

Key equipment for the manoeuvrability are rudders, fixed fins, jet thrusters, propellers, ducts and waterjets. However it is not practical to determine this for every ship which is nearby. Therefore a more statistical approach is taken using comparable ships.

### Prediction with limited data

Own vessel input comes from sea-trial, other vessels based on received information via AIS. DWT, L, B, speed, etc.

# Filter situation

Input from static objects shown on the map

## COLREGs

most important COLREG criteria are: - minimal crossing angle - minimal distance starboard - minimal distance portside - minimal distance rear - voorkeur port-port side crossing

## Traffic separation schemes

input from local authorities

## Navigational aids

map/radar/etc.

## Accepted probabilities

Which probabilities can be ignored to speed-up calculation

## Other filters

Significant wave height/ weather/ windspeed

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