MSc Thesis

New TITLE desribing the research

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April 3, 2018

TU Delft

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MSc Thesis

ADD NEW TITLE

Make new title

April 3, 2018

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Notes

Make new title . . . .
Are these really relevant accidents, add more/other? 4
it this the complete list? 8
make a cleaner infographic showing the different parts of the bridge 8
Is this relevant, if yes, describe different parts 9
Reference to inforgraphic with time-line unmanned/autonomous levels 11
give more info on projects and why my research has added value to them. 12
more info on JIP 12
Make infographic 12
update with info from IRYOON 13
Make model in same style as infographic and situation sketches 16
Make clear visualizations of scenarios 19
Add maps of situations 19
add user stories to appendix 20
describe formula to determine crossingpoint of line 36
CPA calculation 36

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

GPS Global Positioning System

GT Gross Tonnage

IEC International Electrotechnical Commission

IHO International Hydrographic Organization

IMO International Maritime Organization

JIP Joint Industry Project

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

Preface ii

Abstract iii

Glossary iv

Introduction 1

I Sailing from manned to autonomous 3

1 Current situation at the bridge 4
1.1 Accidents 4
1.2 Means of communication 8
1.3 The bridge 8

2 Steps towards the future 10
2.1 Why autonomous and unmanned shipping 10
2.2 Projects 11
2.3 Other stakeholders 13
2.4 Possible use cases 13
2.5 Changes in communication 13
2.6 Challenges when combining unmanned and manned vessel 13

II Conceptual design 15

3 Abstract model 16
3.1 Ship characteristics 16
3.2 Influencing factors 17
3.3 Information and communication 17
3.4 Situational awareness 17

4 Scenarios 19
4.1 Standard situations 19
4.2 Real scenarios 19

5 Basic design 20
5.1 Requirements 20
5.2 User stories 20
5.3 User interactions 21
5.4 Assumptions 21

III Simulation 22

6 Building and verification 23
6.1 Model and classes 23
6.2 Methods 23

6.3 Probability index 23
6.4 Routeplanner 23
6.5 Estimation of characteristics 23
6.6 Manoeuvring capability model 23
6.7 Mental model 23

7 Implementation of scenario's 24

IV Reality 25

8 Validation of strategies 26
8.1 Are strategies realistic 26
8.2 Factors not taken into account 26
8.3 EXTEND: with more sections 26

9 Validation of communication 27
9.1 Clear intentions 27
9.2 Risk of information overload 27
9.3 Desired input 27

10 Optimization of communication 28
10.1 Safe motion parameters 28
10.2 EXTEND: with more sections 28

V Wrap-up 29

11 Results 30

12 Conclusion 31
12.1 Answers to research questions 31
12.2 Recommendations for future research 31

VI TEMPORARY: Old text 32

Bibliography 37

Introduction

Considering the major projects within the maritime industry, can be assumed that unmanned and autonomous shipping are getting closer. By taking out seafarers from the chain of command, human errors can be avoided. However taking out humans will lead to more challenges when it comes to communication. Communication is used to share information on the intentions or discuss future actions. Thus to ensure the safety of all vessels; manned, unmanned, remote, automated and autonomous. The question which should be asked is: How do other (manned) vessels know the intentions of other vessels, while there is limited communication possible? This is most relevant when sharing short term intentions, as decisions must be made within minutes or even shorter. On the change course or speed, in order to avoid critical situations.

Problem statement

A computer might like to have as much information as possible. But in case of manned vessels this is not practical, as this will results in an information overload of the crew and communication channels [CCNR(2017)]. Currently is secured in two ways, how intentions of other vessel can be acquired. First and foremost are the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs)[IMO(1972)], rules applicable to all vessels, as these rules are concrete these can be programmed and used also by autonomous vessels. 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 also used to ensure that intentions are clear.

To make autonomous shipping possible, autonomous vessels should know how to communicate their intentions. Doing this by behaving in a predictable manner and without overloading the different VHF channels (including AIS). Other options are to develop a new system and stay away with autonomous vessels or from other vessels. This will be much harder to implement, but still the way intentions are shared should be optimized. This is done by making sure that the radio is used correctly, clear signs which can be interpreted from the behavior and data exchange in other ways. Which all ensures that other vessels know enough about the intentions to anticipate correctly, without overloading the communication channels.

To do this optimization, there should be taken into account that different vessels have different expectations for other vessels, characteristics which determine the manoeuvrability and strategies for specific situations. As a long and heavy ship will mostly go straight ahead at a similar speed, thus resulting in a predictable path which will be sailed. While a small tug boat might move around much more. And therefore be in situations which would be a collision course for others. While it is necessary to think minutes ahead with a long and heavy ship, this is much shorter for a small tug boat. This time-domain for decision making depends not only on the ship characteristics, but also the waterway characteristics such as depth, traffic separation schemes and harbor entrances.

The first option to optimize the communication of intentions is by taking out radio communication completely. Combining the time-domain for decision making of your own vessel, and estimating when others need to make a decision and which decisions they might make. It is possible to determine when and which decision will lead to an unimpeded voyage for yourself. Where an unimpeded voyage means that no communication via VHF-radio is needed to ensure a safe passage with no (perceived) risk.

By adjusting the course based on this information, the need for radio communication is taken out. This will mean less pressure on the crew and less challenges when introducing autonomous vessels. However, to form a register of possible decisions, there is also input needed. These still have to be received via other means than radio communication. This is done using for example sensors like radar, communication via AIS or a new system. The raw data from these sources will together form the information needed to create the decision domain. The first step to known which sources are needed, is to know which information is desired. This will also be part of this research, beside looking into the forming a the decision domain.

Research questions

To enable the step towards autonomous shipping, a start is made with a qualitative research. Focused on forming the above mentioned register of possible decisions with the right information. And from here deciding what the decisions should be. By looking into which information is most relevant for the different vessels. This will be done from two perspectives within the domains of Maritime Technology and Computer Science. Resulting in two research questions:

> *How do ship characteristics influence the time-domain for decision making to ensure an unimpeded voyage?*
>
> *Which information must be shared between vessels, to ensure that possible decisions of other vessels can be predicted correctly?*

Report structure

Within the project, several steps will be taken. At first more background is given on the current state of the maritime industry in respect to autonomous sailing and ways of communication. Thereby mentioning how the knowledge developed in this research, will help to tackle challenges in current projects. Next a more detailed plan of approach for the research is given, including an abstract model which shows how ship characteristics and gathered information influence the possible decisions and ability to estimate intentions.

This model can be used to form strategies to cope with specific situations. To validate if it is possible to use this model, different scenarios are defined which are used as test-cases. These scenarios will be tested within a simulated environment. Requirements for this simulation are first defined, which lead to user stories and an implementation. This simulation is finally validated together with seafarers on the quality of the communication and if ships act realistically within the different scenarios. This is used to give an qualitative advice on how to optimize communication, or more specifically which information should be shared.

Part I

Sailing from manned to autonomous

1 Current situation at the bridge

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 need to be taken. To ensure all seafarers get home safely.

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. Some were reactions on major accidents which occurred. Such asthe disaster with the TITANIC in April 1912, which leaded to the international treaty International Convention for the Safety of Life at Sea (SOLAS). But also the new innovations, such as the introduction of Global Positioning System (GPS) for civilian use. Combining this with the already existing Very High Frequency radio (VHF). This led to the introduction of Automatic Identification System, part of VDES (AIS). Which became obligated for all passenger ships and other commercial vessels over 300 Gross Tonnage (GT), by a mandate from International Maritime Organization (IMO) in 2002. Despite these 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 how this is used.

1.1 Accidents

Below three accidents are discussed, showing the importance of proper communication. 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

Are these really relevant acci- dents, add more/other?

1.1.1 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 1.1. 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 1.1: 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 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)]

1.1.2 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 1.2. 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.

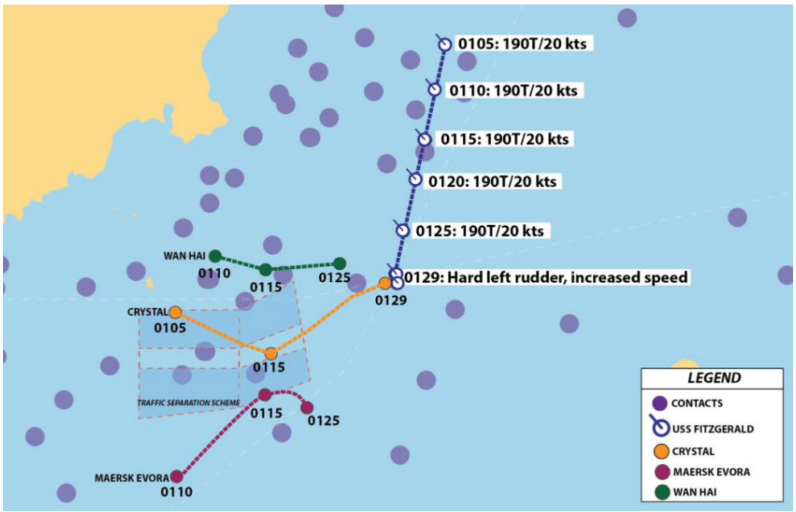

Figure 1.2: Illutstration map of approximate collision location

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)]

1.1.3 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 1.3. 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.

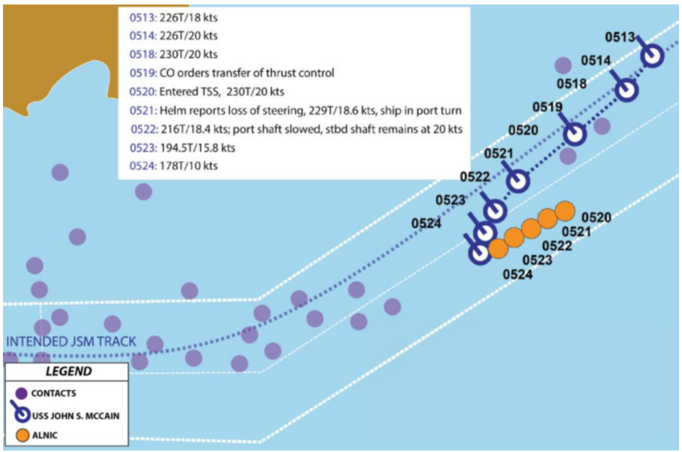

Figure 1.3: Illutstration map of approximate collision location

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)]

1.2 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 AIS
- Horn

http://www.bigoceandata.com/news/brief-history-ais/

it this the complete list?

1.3 The bridge

According to DNV-GL, the bridge of a vessel can be separated into four elements. The human operator, procedures, technical system and the human-machine interface. As shown in figure 1.4 [DNV GL(2011)]. 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 these should be used.

make a cleaner info-graphic showing the different parts of the bridge

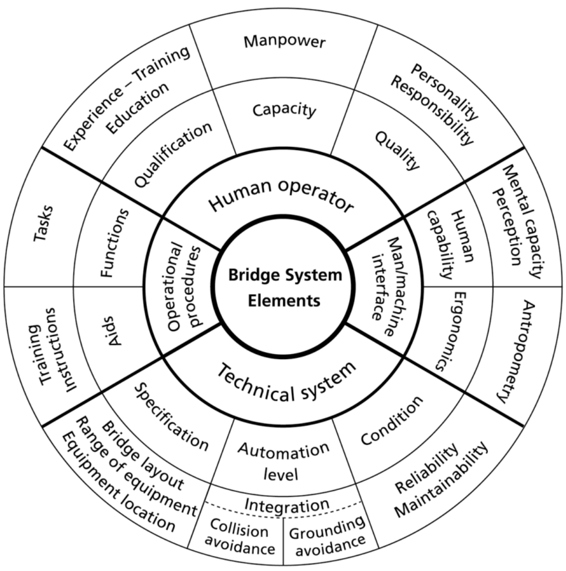

Figure 1.4: Bridge system elements

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 by all available means appropriate in the prevailing circumstances and conditions. To make a complete assessment of the situation, including the risk of collision, grounding and other hazards to navigation.

Is this relevant, if yes, describe different parts

1.3.1 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.
How much automation is used now, plotter, combining ECDIS and Radar.
Collision avoidance and other warning systems, also not related to navigation.

1.3.2 Man/machine interface

How is information used. Mention parts on information overload. Thereby also the difference between ships. Officer walking around on big ship, vs small bridge on a tug for example.

1.3.3 Procedures

Training, education and protocols. How are procedures developed, use maritime support knowledge on writing them.

1.3.4 Human operator

How does it go in practice, experience. Relation with shifts and information overload, or the other side with a boring shift, when out of the blue full attention is desired. Importance of culture to the decision making process.

2 | Steps towards the future

The shipping industry is traditionally driven by regulations and making profit within these given boundaries. Many CEOs state that digitalization and de-carbonization are watchwords for the coming decade. Current projects funded by the EU aim at sustainable growth. This means, be competitive while also reducing the environmental footprint and improve the safety of people working in the industry. [Eriksen(2017)] [European Commision(2017)] This research will mainly focus on improving safety at sea, the digitalization is most relevant here, certainly when it comes to autonomous and unmanned ships. A description will be given of the steps which will most likely be taken in the coming years.

2.1 Why autonomous and unmanned shipping

Focusing on the digitalization, ships will become more sophisticated. More data is generated by sensors, improved connectivity and new ways to visualize 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. But further ahead this might result in unmanned vessels, which are operated remotely. In parallel there is the transition where people are taken out the chain of commands, which will result in automated or completely autonomous vessels. The main arguments heard for the transition towards autonomous or unmanned ships:

- *Improved safety*, as most accidents are caused by human errors. Thereby will there be less crew at the ship, thus less crew is at risk when an accident occurs.
- *Lower cost*, as insurance goes down due to improved safety. Thereby is manning a large portion of total cost. With more automation, less crew is needed, although they need to be schooled better.
- *Higher productivity*, when there is better usage of data and communication. Thereby comes that computers don't have to work in shifts to go home or take breaks.
- *Improve competitiveness*, as tankers which are traded for example, do not have to enter a harbor to get fresh supplies.
- *More comfort and attractiveness industry*, as people can have more regular hours to work and do not have to be away for many weeks when working remote.

Thereby are maritime trade volumes expected to increase in the future and accordingly the numbers of ships needed to transport the freight will grow, as will the number of seamen required to operate the vessels. At the same time European shipping faces a lack of seafaring personnel already today. An often cited reason for this lies in the unattractiveness of seagoing professions, especially for youngsters. To some extend this is caused by seafaring's inherent problem of lacking family friendliness and the high degree of isolation from social life that comes along with working on a seagoing ship. The current trend towards slower sailing speeds justified by ecologic and economic considerations increases the length of the ship's voyage and with that the time seamen spend on sea even further.

Here, the unmanned autonomous vessel represents a way out of the impasse of a shortage in the supply of seafarer due to the job's perceived unattractiveness and a growing demand for seafarer caused by slow steaming and increasing transport volumes.On the one hand, it could reduce the expected pressure on the labor market for seafarer as it would enable, at least partly, to reduce the labor intensity of ship operation. On the other hand, routine tasks on board would be automated and only the demanding but interesting navigational and technical jobs transferred from ship to a shore side operation center making "seafaring" jobs more attractive and family friendly than today. Furthermore, economic and environmental benefits are also expected when implementing unmanned shipping. [MUNIN(2016)]

The different projects around the world, working on the transition towards autonomous or unmanned vessel, are mentioned with their current status.

Reference to infor-graphic with time-line un-manned/autonom levels

2.2 Projects

The research project MUNIN has been one of the major projects by a consortium of ship-builders 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 between 2013 and 2016. 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.
- Examining 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)]. They have showed the importance of developing a method to determine intentions of other vessels and systems which are needed. But did not yet make the step towards developing such a method, which will be done in this report.

2.2.1 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 vessel, 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.

Other projects which have clearly published there vision for the future are: - DIMECC with (One Sea)
- AAWA
- ReVolt

give more info on projects and why my research has added value to them.

Since June 2017 is Rolls-Royce also involved in the unmanned cargo ship development alliance, which is initiated by Asian companies and classification bureaus. In the Netherlands a Joint Industry Project (JIP) has started on autonomous shipping.

more info on JIP

Make inforgraphic: combining different roadmaps, such as DIMECC and Rolls royce, thereby also showing the different levels of automation and unmanned

Make infographic

2.2.2 Industry projects

Beside the visionary projects mentioned before, some companies are also coming with real results. Often funded by customers of shipping companies. 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. A partly Dutch project is the Roboat, where a fleet of small pontoons will 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.

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 (SMASH) focus on combining technological developments within different parts of the inland shipping industry in the Netherlands. This will help to steer ships remotely, enable intelligent exchange 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)].

2.3 Other stakeholders

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

update with info from IRYOON

2.4 Possible use cases

Summarizing the projects, based on this what would be likely 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)

2.5 Changes in communication

Describe the impact on the different facets of the bridge (Technical system, man/machine interface, procedures, human operator). e.g: VDES

2.6 Challenges when combining unmanned and manned vessel

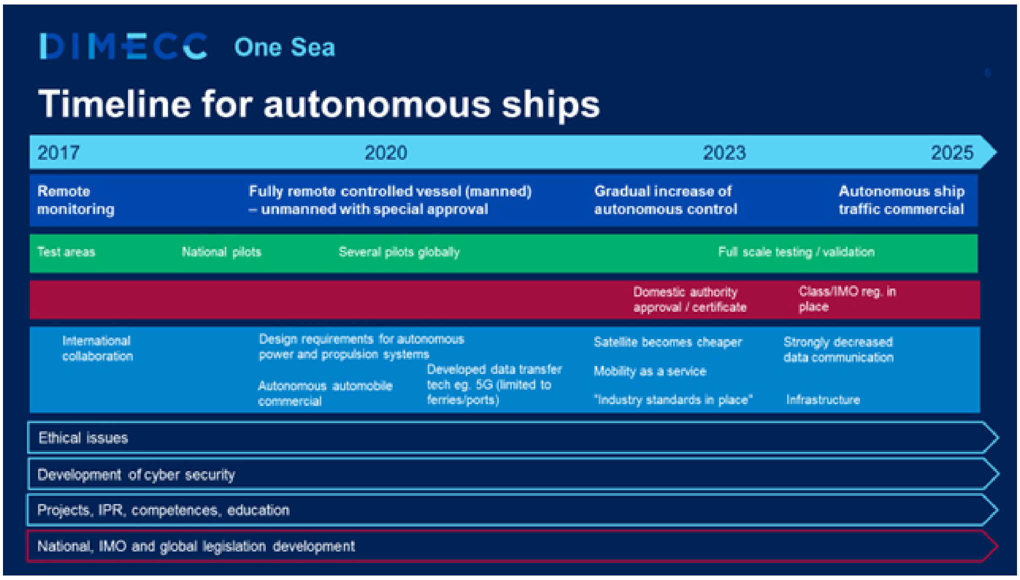

Figure 2.1: EXAMPLE-infographic: Timeline for autonomous ships by DIMECC

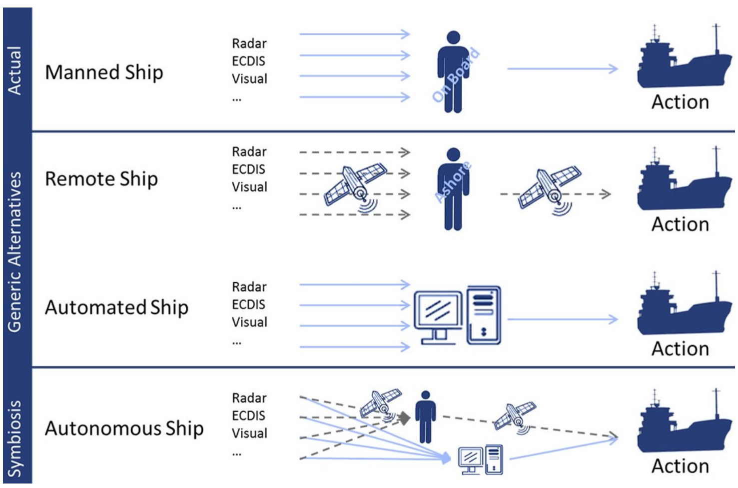

Figure 2.2: EXAMPLE-infographic: From manned to autonomous ships

Part II

Conceptual design

3 | Abstract model

As mentioned before, first must be known how ship characteristics and gathered information influence the possible decisions and ability to estimate intentions. This is made understandable using an abstract model. Here is also a separation made between the relevance of the subjects for Maritime Technology and Computer Science. The reason to make this model is to have a list of topics relevant to the strategy which will be developed for the specific scenarios. In figure 3.1 a visual of the abstract model is shown. In the next section different parts of the model will be discussed in more detail.

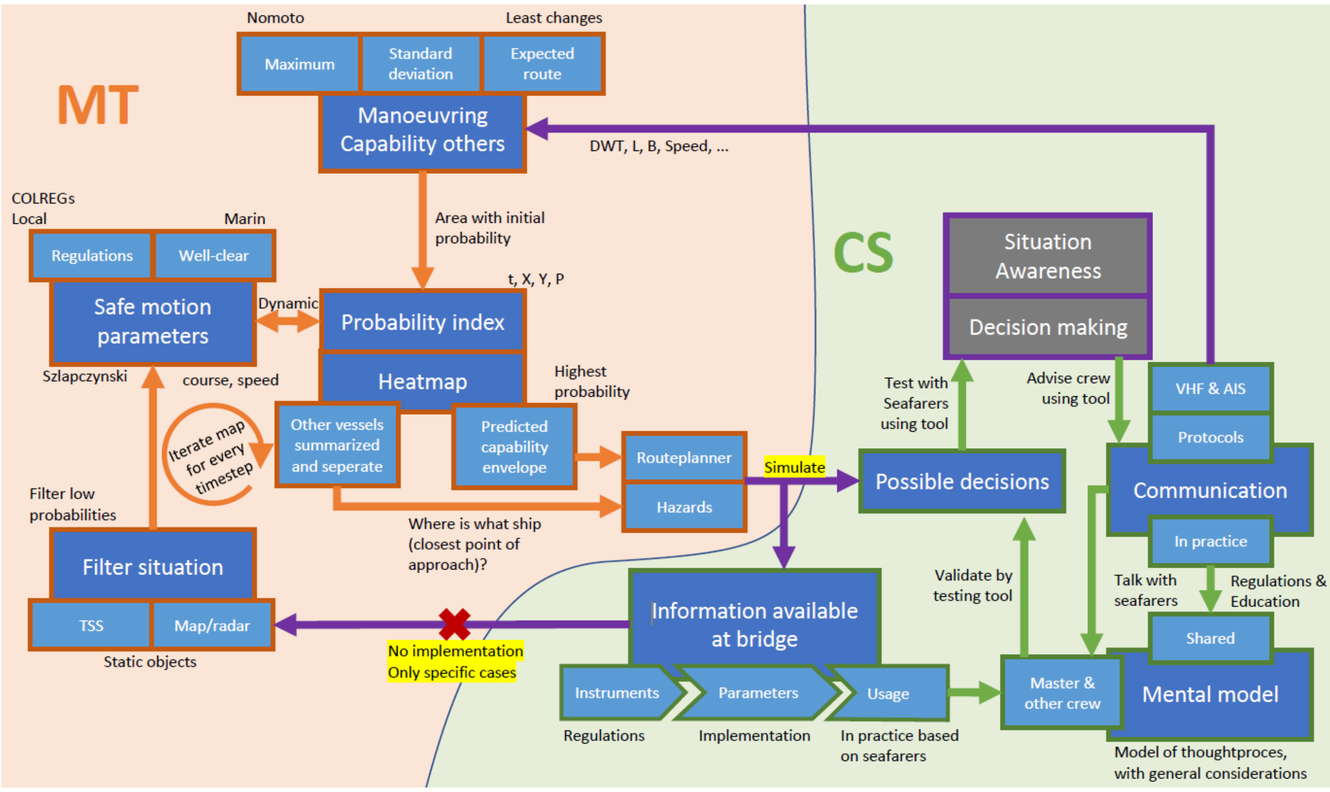

Figure 3.1: Abstract model

Make model in same style as infographic and situation sketches

3.1 Ship characteristics

The main block on 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 much easier and will most likely occur more often.

Therefore the capability of the ship is split up in three categories, expected location, likely change of course 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 it 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.

3.2 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 estimated safety domains for each ship. Leading to courses and speeds which are safe to sail [Szlapczynski and Szlapczynska(2017]. While also incorporating 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, where another ship will likely be. When looked at the highest probability this will show the most likely route for each vessel. Which can be used to advise on the route planning of the own vessel. As the probabilities combined with a threshold will result in a set of possible decisions.

3.3 Information and communication

Already mentioned is the impact of other vessels and objects on the probability that a ship will be at a specific location. But to know this impact, information has to be gathered from different parameters. Thereby should be looked if the current parameters are sufficient and can be trusted, or if other equipment or instruments should be installed.

Currently vision and radio communication are very important ways to gather information. These types of information are difficult to gather using computers, currently many researches happen on for example Lidar and other methods. Therefore this research will focus on what information is needed, not how it is gathered. Although developments within technologies to gather this information will be taken into account to develop eventually the strategies. For example related to AIS, VHF Data Exchange System (VDES) and different protocols.

3.4 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.

4 | Scenarios

To gain more insight into the decision process, and when information is desired so the right decision can be made in time simulations are done. These will be done for several standard situations and real scenarios which occur at the North Sea.

4.1 Standard situations

To verify if the tool is working as expected, different standard situations and scenarios are tested. Which are also used to determine the thresholds to execute different strategies. The situations, scenarios and related strategies are shown in table 4.1.

Situation	Scenario	Strategy
Simple crossing	other ship from port side	passing at the front
Simple crossing	other ship from port side	passing at the back
Simple crossing	other ship from starboard	passing at the front
Simple crossing	other ship from starboard	passing at the back
Crossing	with a small angle	passing at the front, with larger angle
Crossing	with a small angle	passing at the back, with larger angle
Take-over	ship in front	wait till there is enough space
Enter traffic lane	to port side with ship from starboard	get in front
Enter traffic lane	to port side with ship from port	get in front
Enter traffic lane	to starboard side with ship from port	get in front
Enter traffic lane	to starboard side with ship from starboard	leading to no interaction

Table 4.1: Standard scenario's

During the simulation an analyses is made what the ships perceive as hazards. This also depends on the acceptable distance for a well-clear situation. By varying this distance, can be seen if strategies will change. Thereby will be verified if COLREGs are followed. Varying the shared information will result in a better understanding of the mental model in those situations and can be seen what the effect is on recognizing hazards in the correct way.

Make clear visualizations of scenarios

4.2 Real scenarios

Two scenarios will be simulated, first a situation such as the crash between Al Oraiq and Flinterstar as described in section 1.1.1. Where there will be different strategies, if the Al Oraiq took other decisions, if the Flinterstart took other decisions and if both used different strategies.

The second situation is the entering of the Maasgeul from the Beerkanaal at the end of the Maasvlakte, specifically in the situation when there are multiple vessels already coming from the Maasgeul, Nieuwe Waterweg and possibly the Callandkanaal.

Add maps of situations

5 Basic design

To test the different scenarios a tool will be build. This tool will be able to simulate the scenarios to get more insight why decisions are made. Full scale testing will cost much more time and effort as it is harder to control. The development will be based on the principles from the Agile Manifesto, as this has proven to result in effective software. This means there will be a start with a basic tool, which will continuously be improved. Changes in requirements might appear trough out the whole process, to deliver a better tool. Thereby must be kept in mind that working software is the primary measure of progress. This is only possible when the software is sustainable and thus easy to maintain and improve, which is only possible with a good design. Keeping it simple will be key in this process. Thereby reflective moments are needed to check if the chosen path is the right one, or if the direction should be adapted.

5.1 Requirements

The first step is to set the goals or requirements of the software. This doesn't mean it is a full description of the software, but features it should at least have to be able to answer the research questions. The most important requirement is that ships within the simulation behave similarly to ships in reality. This does not necessarily mean that all hydromechanics should be known. But ships should have similar ways of turning and changing speed. This can be based on sea-trials and done using a mapping from current speed, current rotation, rudder angle and throttle to future speed and turning speed. The second requirement should be that it is flexible, in a way that different scenarios can be added and tested easily. Thereby changing ship characteristics, shared information and other inputs. Thirdly, it must be possible to show the register of possible decisions for the different vessels. To be able to validate this with seafarers. Meaning it will be a white box model.

5.2 User stories

The next step is to define users stories from the requirements. User stories are in a form: *"As a [user] I want [action] so that [result]"*. Extending them with an acceptance criteria this will result in the features which should be implemented.

Within this application there will be different roles. For which these user stories can be used. Below these are described:

- *Operator*. The person who set-up the simulation and fills in the different properties for the ships and specific scenario.
- *Viewer*. Someone who uses the application to view a specific scenario. Thereby trying to answer the research questions.
- *Ship*. Object in the map which is used by the simulation. But to work correctly it also had needs for information.

Some examples of those user stories are given below. All users stories can be found in appendix XXX..

add user stories to appendix

- As an operator, I want to add vessels to the map, by selecting them in a list, so that they become part of the simulation.
  Acceptance criteria: Ship visualized and other ships start receiving information.
- As a viewer, I want to to be able to get the belief state, intention and next action of a ship, so that I can verify if it is what I expected it to be.
  Acceptance criteria: Belief state, intention and next action are shown.
- As a ship, I want to be able to predict the path of other vessels, so that I can make my decisions based on this.
  Acceptance criteria: correctly updated belief state about other vessels.

5.3 User interactions

What should de different modules do

5.4 Assumptions

Questions, clarifications and scope

Part III

Simulation

6 | Building and verification

6.1 Model and classes

6.2 Methods

6.3 Probability index

what should the polygons show

6.4 Routeplanner

Including the usage of waypoints with weights

6.5 Estimation of characteristics

Deadweight to displacement for example

6.6 Manoeuvring capability model

Estimation of relation between throttle, loss of speed while turning. Thus a mapping from current speed, current rotation, rudder angle and throttle to future speed and turning speed

6.7 Mental model

onthologie

7 | Implementation of scenario's

Testing of the scenario's from chapter 4.

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

Part IV

Reality

8 | Validation of strategies

8.1 Are strategies realistic

8.2 Factors not taken into account

Germans for example do sometimes alter the off-set of AIS to avoid confusing with radar image. As captains should use radar instead of AIS information to navigate. AIS is not reliable enough, but with small errors captains still do it, so giving it a large off-set will force captains to use radar.

other factors equipment, flagstate, origin of crew, etc.

8.3 EXTEND: with more sections

9 | Validation of communication

together with seafarers

9.1 Clear intentions

9.2 Risk of information overload

9.3 Desired input

Do they want this information at the momtent

10 | Optimization of communication

what is needed to improve the knowledge on intentions

10.1 Safe motion parameters

10.2 EXTEND: with more sections

Part V

Wrap-up

11 | Results

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

12 | Conclusion

12.1 Answers to research questions

12.2 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 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

CPA calculation

Input

Nomoto, more detailed is Norrbin equation

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

Bibliography

[Backer(2015)] Philippe D E Backer. Report on the joint investigation of the collision between the LNG Carrier mts AL ORAIQ and the mv FLINTERSTAR. Technical Report October, 2015.

[CCNR(2017)] CCNR. Inland AIS devices and electronic chart display systems on the river Rhine. pages 1–94, 2017.

[DNV GL(2011)] DNV GL. Special equipment and systems - nautical safety. *Rules and regulations*, 2011. ISSN 0028-0836. doi: 10.1038/147264c0.

[Eriksen(2017)] Remi Eriksen. Technology Outlook 2025, 2017. URL `https://to2025.dnvgl.com/`.

[European Commision(2017)] European Commision. No Title, 2017. URL `https://ec.europa.eu/maritimeaffairs/policy/blue{_}growth{_}en`.

[IMO(1972)] IMO. Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs), 1972. URL `http://www.imo.org/en/About/conventions/listofconventions/pages/colreg.aspx`.

[MUNIN(2016)] MUNIN. About MUNIN, 2016. URL `http://www.unmanned-ship.org/munin/about/`.

[Sames(2017)] Pierre C Sames. Unmanned ships on the horizon - DNV GL, 2017. URL `https://www.dnvgl.com/article/unmanned-ships-on-the-horizon-94273`.

[SMASH(2017)] SMASH. Elektrisch containerschip Gouwenaar 2, 2017. URL `https://smartshippingchallenge.nl/initiatieven-en-innovaties/electrisch-containerschip-gouwenaar`.

[Szlapczynski and Szlapczynska(2017] Rafal Szlapczynski and Joanna Szlapczynska. A method of determining and visualizing safe motion parameters of a ship navigating in restricted waters. *Ocean Engineering*, 129(September 2016):363–373, 2017. ISSN 00298018. doi: 10.1016/j.oceaneng.2016.11.044. URL `http://dx.doi.org/10.1016/j.oceaneng.2016.11.044`.

[US Navy(2017)] US Navy. Report on the collision between USS Fitzgerald and motor vessel ACX Crystal. Technical report, 2017.

[Wilson(2017)] Jonathan Wilson. Rolls-Royce Marine unveils 'Electric Blue' modular smart shipping concept, 2017. URL `https://eandt.theiet.org/content/articles/2017/02/rolls-royce-marine-unveils-electric-blue-modular-smart-shipping-concept/`.