MSc Thesis

New TITLE desribing the research

Ingmar Wever (4161041)
June 7, 2018

TU Delft

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MSc Thesis

ADD NEW TITLE

Make new title

June 7, 2018

Student:	Ingmar Wever	4161041
Project duration:	September 2017 – July 2018	
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

sCE situated Cognitive Engineering

AIS Automatic Identification System, part of VDES

AMS Alarm Management System

ARPA Automatic Radar Plotting Aid

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

CPA Closest point of approach

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

no-UI Non-visual User Interaction

SMCP Standard of Maritime Communication Phrases

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

Introduction

Considering the major projects within the maritime industry [SMASH(2017)] [Eriksen(2017)] [MUNIN(2016)] [Sames(2017)] [Rolls-Royce(2015)] [Waterborne(2016)]. It can be assumed that unmanned and autonomous shipping are getting closer. Mitigating human errors can be done by taking out seafarers from the chain of command, however this will introduce new challenges. For example, the communication with other vessels and decision making in unknown situations. Communication is used to share information on the intentions or discuss future actions. This means the safety of all vessels (manned, unmanned, remote, automated and autonomous) can be ensured. The question which should be asked is: When do vessels have to know each others intentions, certainly when only limited communication is possible? This is most relevant when sharing short term intentions which determine the path. As decisions must be made on changes for the path, within minutes or even shorter.

Context

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. They can be seen as ship separation rules, which guide to make early and correct alterations to the course. As it is safer to make early adjustments to course or speed, than to spend too much time using Very High Frequency radio (VHF), Automatic Radar Plotting Aid (ARPA) or Electronic Chart Display Information System (ECDIS) to make an assesment. These rules do also apply to autonomous ships, thereby is it possible in most cases to program them into a decision model. 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 must be used to ensure that intentions are clear, as the COLREGs are not always sufficient anymore in these cases.

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, or separate autonomous traffic from other vessels. This will be much harder to implement, but even in those cases, the manner of sharing intentions should still be worked out. 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 communication channels.

To solve the problem, different parts should be taken into account, different vessels have different expectations for other vessels, as characteristics which determine the manoeuvrability differ and strategies for specific situations depend on many factors. For example will a cargo ship follow a fairly predictable path. While a small tug boat might move around much more. This means much more false positives on potentional collisions with other vessels. The manoeuvrability also means that it is necessary to think ahead several minutes with a long and heavy ship, while 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.

Problem statement

This research will separated into two parts. The first will consider the situation where verbal radio communication is taken out completely. In this case decisions must be made clear earlier and more bold to ensure others are aware of your intentions and can anticipate correctly to this. To ensure an unimpeded voyage this must be done in time. This so-called time-domain for decision making can be determined by taking several steps. First the possible decisions must be determined, these are mapped to possible positions using the manoeuvring capabilities of the ship. Combing these results with similar analysis for surrounding ships, the likely decisions can be determined which will lead to an unimpeded voyage. Where an unimpeded voyage means that no verbal communication via VHF-radio is needed, to ensure a passage without perceived risk.

The second part will focus on sharing information to optimize estimation of the time-domain. Much has been done and is still under development on how to get more information to the seafarer. However more information is not the solution. The right information is more important. In the situation as described in the first part, there will be no verbal communication. Therefor other means of communication are needed. 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. Thereby will be determined what the impact of different information is on the decision making process.

Both parts will model the steps from interpreting information and making strategies based on this information, also know as situational awareness of the vessels. To test these models, a tool is developed. In this tool situations at sea can be simulated. The input will be the different models developed in the above described parts, together with situations and sea. The simulation shows which strategies are chosen by the different sets in different scenarios, when different models are implemented.

Add figure with line with available information, certainty correct decision is being made. Supporting why research is relevant.

Research questions

The above mentioned models are all steps towards autonomous shipping. This research will be a start, including mostly qualitative research. Eventually it is the aim to use the models to form a register of possible decisions. 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 that the chosen strategy will result in a safe minimal distance between vessels?*
>
> *Which information must be shared between vessels, to ensure that likely decisions of other vessels can be predicted correctly?*

Report structure

Within the project, several steps will be taken. At first more context is given on the current

link structure to chapters

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. Next a more detailed plan of approach for the development of an application is given, showing which factors should be taken into account and how this will eventually lead to an application in which models can be verified and validated.

Followed by two different parts. First on the forming of a time-domain for decision making. Within a simulation environment, a model is formed which is based on the current situation for sharing information. This model is used to form strategies to cope with specific situations which occur while sailing. 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 the simulation 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.

The next part will use the previously developed model where variation are made to the information which will be shared between vessels. To determine which information should be shared in more complex situations where current systems for sharing information are not sufficient. Thereby is studied what the impact is of varying the information on the previously mentioned strategies to cope with the specific situations.

Part I

Steps towards safe autonomous shipping

Safety at sea has been a relevant topic as long as ships exist. There are several factors which have a big influence on safety. First and foremost is communication in all the ways where information is shared. Before the invention of radio communication, ships literally lost all connection with the shore and other ships when setting sail. Flags were used when ships were close to others ships or to the shore. This form of communication was not complete as it only gave limited insight in the intentions of other vessels for example.

New technologies lead to new ways for communication, which subsequently lead to a safer industry. But new technologies also lead to complexer situations. As ships get bigger and perform more complex operations, resulting in less manoeuvrability. In those situations it is very important to share the right information. The current situation of the maritime is assessed together with a summary of likely new technologies related to navigational safety.

To give insight in the current situation of the shipping industry, first some accidents are discussed and which lessons can be learned from this. This is followed by a description of the current means for communication. This eventually all comes back to the different elements of the bridge. Giving insight in how accidents occur and what is currently available to prevent them. This is a basis for technologies which will be developed at the moment, and are discussed in the last chapter of this part. The above mentioned knowledge is used as a starting point for the model to gain insight when decisions should be made in current operations to improve safety.

1 | Current systems to improve safety

To improve the system and procedures, the first step is to know what is currently available. Thereby should be known which information these systems can give, and how these systems are used. Therefor a description is given of the current means for communication. These can all be related to different elements of the bridge, to make it more tangible.

1.1 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
  - Positions
  - 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?

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

1.2 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 1.1 [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 infographic showing the different parts of the bridge

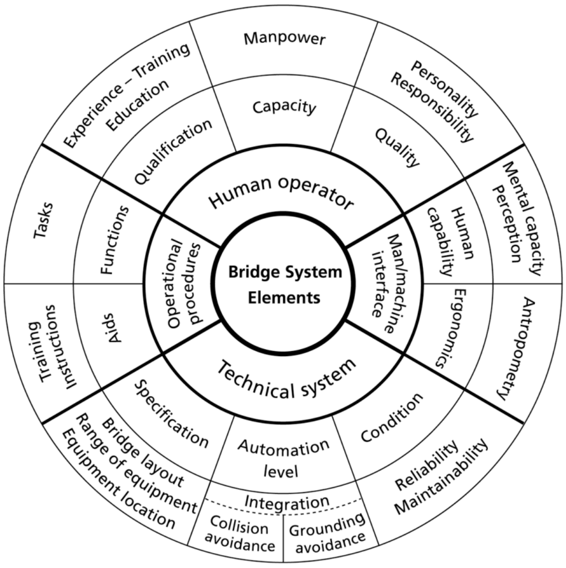

Figure 1.1: Bridge system elements

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

1.2.1 Technical system

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

- Navigation radar with radar (ARPA)
- 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.

Categorize into communication, situational awareness, etc.

Collision avoidance and other warning systems, also not related to navigation.

1.2.2 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.

1.2.3 Procedures

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

1.2.4 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.

1.3 Relevant systems for autonomous shipping

Not everything is relevant to other ships, in order to determine the possible decisions. This is only: information from radar, information available in AIS (where reliability must be considered), warning systems, etc...

Mention the problems with ECDIS/AIS (old information, not correct as mentioned by loodswezen), as I refer to this in snapshots scenario description.

2 Accidents

In the last centuries much have changed. Some were reactions on major accidents which occurred. Such as the 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 VHF. This led to the introduction of 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.

Below four accidents are discussed, showing the importance of proper communication on different levels. The accidents which will be discussed are, followed by the lesson learned from theses accidents:

- 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
- Collision between MV CONTI PERIDOT and MV CARLA MAERSK

Are these really relevant accidents, add more/other?

Add images of resulting damages

2.1 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 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)]

2.2 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.

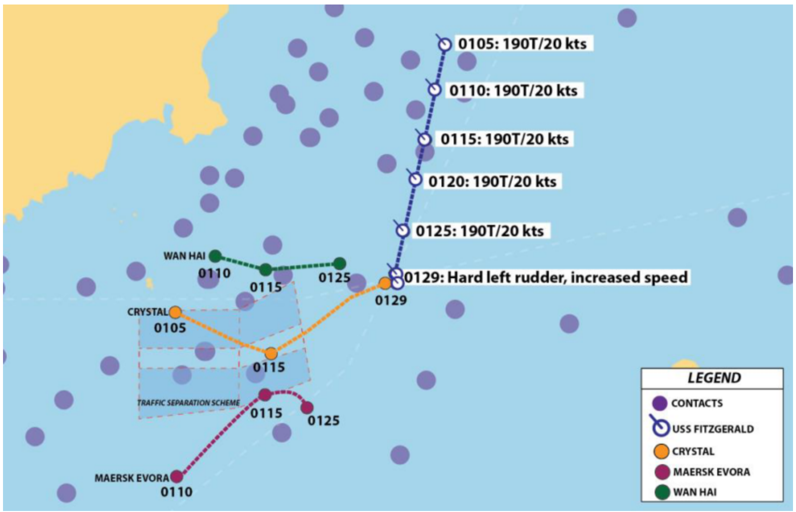

Figure 2.2: Illutstration map of approximate collision location

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)]

2.3 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.

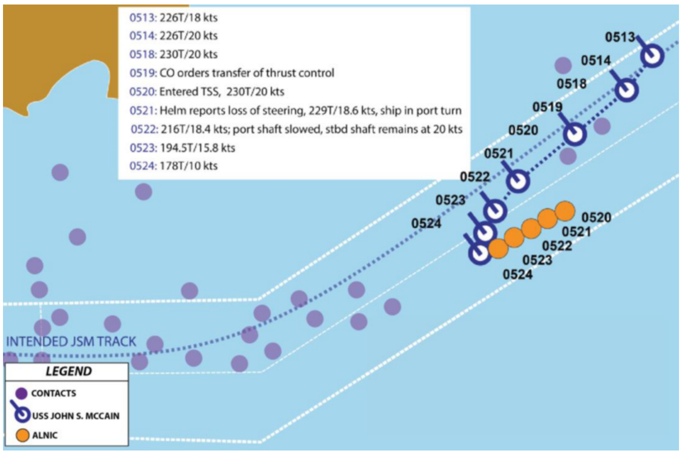

Figure 2.3: Illutstration map of approximate collision location

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)]

2.4 MV CONTI PERIDOT and MV CARLA MAERSK

The last accident which will be discussed is the collision between MV CONTI PERIDOT and MV CARLA MAERSK on 9th March 2015. At 12:30 central daylight time, the the inbound bulk carrier CONTI PERIDOT collided with the outbound tanker CARLA MAERSK in the Houston Ship Channel near Morgan's Point, Texas. The collision occurred in restricted visibility after the pilot on the CONTI PERIDOT was unable to control the heading fluctuations that the bulk carrier was experiencing during the transit. As a result, the CONTI PERIDOT crossed the channel into the path of the CARLA MAERSK. No one on board either ship was injured in the collision, but an estimated 2,100 barrels (88,200 gallons) of methyl tert-butyl ether spilled from the CARLA MAERSK, and the two vessels sustained about $8.2 million in total damage. In figure 2.4 the fluctuations in heading can be seen of the CONTI PERIDOT.

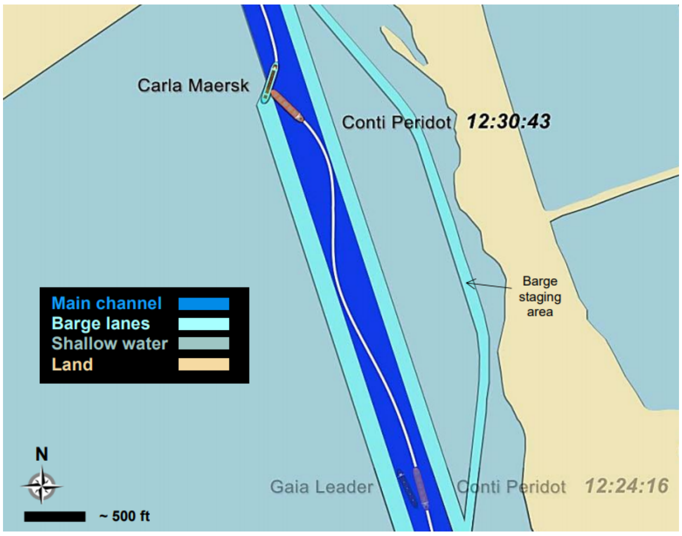

Figure 2.4: Illutstration map of approximate collision location

Several safety issues were identified by the National Transportation Safety Board. Inadequate bridge resource management: Despite the pilot's difficulty controlling the CONTI PERIDOT's heading leading up to the collision, he and the master did not work together to solve the problem. The pilot did not involve the master because he was unsure whether the master could do anything to help; the master said nothing because he was likely unaware of the vessel's heading fluctuations and may have been generally reluctant to question the pilot. Insufficient pilot communications: Although the pilot on the CONTI PERIDOT was having difficulty controlling the vessel and had an earlier near-miss meeting with an oncoming ship, he did not alert the pilots on subsequent oncoming vessels, including the CARLA MAERSK. Lack of predetermined ship movement strategies during restricted visibility in the Houston Ship Channel: On the day of the accident, local pilot associations determined that the increasing fog was significant enough to suspend pilot boardings of inbound ships. However, piloted vessels already under way continued the transit in the fog. Investigators found no existing predetermined ship movement strategy for piloted vessels already under way at the onset of hazardous weather conditions.

The National Transportation Safety Board determines that the probable cause of the collision between bulk carrier Conti Peridot and tanker Carla Maersk in the Houston Ship Channel was the inability of the pilot on the Conti Peridot to respond appropriately to hydrodynamic forces after meeting another vessel during restricted visibility, and his lack of communication with other vessels about this handling difficulty. Contributing to the circumstances that resulted in the collision was the inadequate bridge resource management between the master and the pilot on the Conti Peridot. [NTSB(2016a)][NTSB(2016b)]

2.5 Lessons learned

For example: Proper bridge resource management is key, warning surrounding vessels if there is limited control is important, strategies for movements in failure modes should be predetermined.

Summaries all lessons learned from the above mentioned accidents

3 | 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. Where they build upon the previously developed technologies mentioned in the previous chapter. A description will be given of the steps which will most likely be taken in the coming years and which challenges they will bring when it comes to communication and safety.

3.1 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 info-graphic with time-line un-manned/autonomous levels

3.2 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.

3.2.1 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

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.

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

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

3.2.2 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)].

more info on JIP and Sovereign

Make infographic

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)].

3.3 Other stakeholders

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

update with info from IRYOON

3.4 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)

3.5 Changes in communication

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

3.6 Challenges when combining unmanned and manned vessel

For unmanned vessels a new system for communication must be developed, as human speech is very hard for computers. The cost of development for this new system depends on the amount of situations it has to cope with. By adjusting the operational strategies for unmanned ships to avoid complex situations as much as possible, these situations can be kept to a minimum. The challenges which have to be tackled are therefore how these ships can avoid complex situations. This means that they have to take decisions well in advance so others are aware of their intentions. Still some challenges are open, as not all complex situations can be avoided. For these cases still must be thought about which information should be shared to make the right decision. Which is related to the question, which systems are needed to share this information.

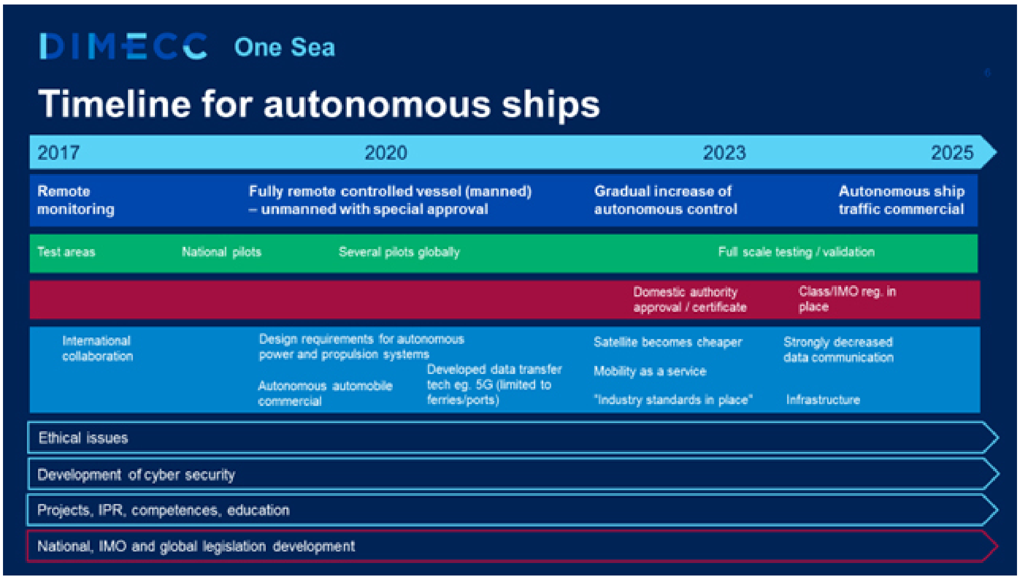

Figure 3.1: EXAMPLE-infographic: Timeline for autonomous ships by DIMECC

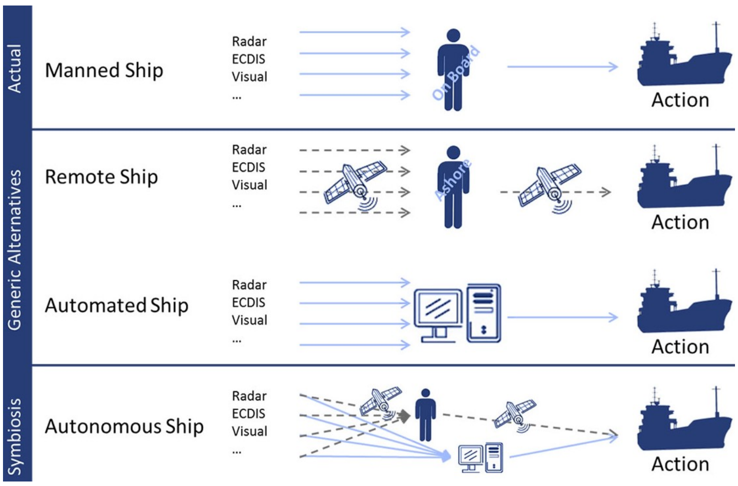

Figure 3.2: EXAMPLE-infographic: From manned to autonomous ships

4 Abstract model

To form the set of possible decisions, different factors should be taken into account. To get insight in these factors, an abstract model is developed. This abstract model will link the creation of a mental model to the physical world, which is key in creating situational awareness. From this model different subjects can be derived, relevant to making the right decision at the right time, which result in the correct strategy to cope with the specific scenarios. In figure 4.1 a visual of the abstract model is shown. In this chapter different parts of the abstract model will be discussed in more detail.

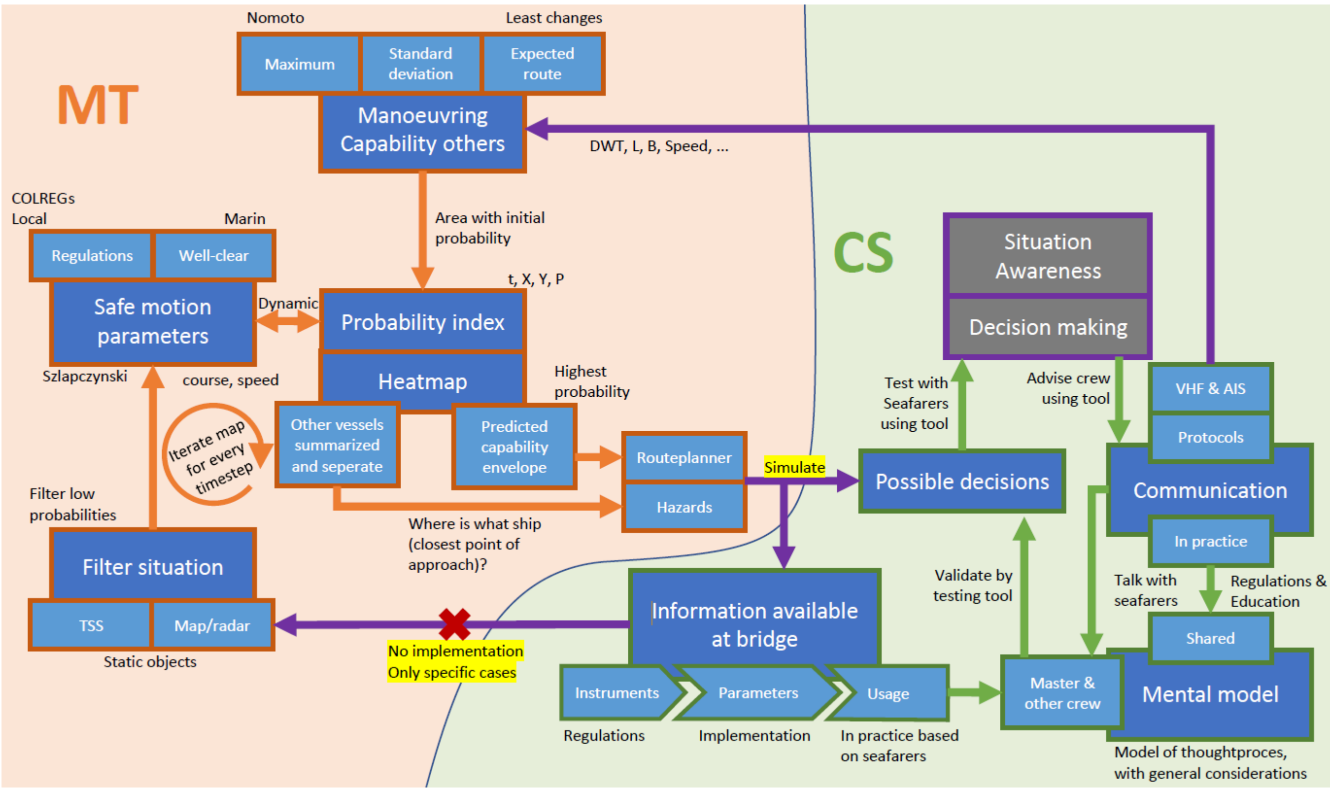

Figure 4.1: Abstract model

Make model in same style as infographic and situation sketches, using blocks as mentioned below, also use notes from Soevereign meeting

4.1 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.

4.2 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. Applicability of rules depends on the ship characteristics. Just as with the natural laws, the probability of getting into 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 ships should follow lanes marked by buoys, and avoid 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.

4.3 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.

4.4 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.

4.5 Focus of this research

This research will focus on criteria for choosing a specific strategy automatically. And in cases this strategy does not work, what kind of interface is needed between crew on other ships and an autonomous ship.

Part II

Relevance of criteria for decision making

The previous part described the context and the steps needed towards autonomous shipping. This chapter will focus on the decision making process. This is currently done by captains, on autonomous ships this should be automated. To accomplish this, criteria must be known on which these decisions can be based.

To determine the criteria, a ship will have to identify the situation and specific scenario first. These determine which criteria are relevant. For different possible strategies these criteria are evaluated. Based on this evaluation, the right strategy can be chosen.

To figure out which criteria are relevant, first two scenario for a standard situation are analysed step-by-step. This means gathering information on for example the location, actors and rules which apply. This will result in a decision tree with criteria, based on the distance and speed between vessels these criteria can be evaluated and be determined which are most relevant. This will result in a lists for possible locations, actors, scenarios and decisions. Collecting these and repeating the process will result in a database. This database can be used to develop a rule-based time-domain decision model.

This model is consecutively implemented into a tool to test if ships act as expected. By more varying the scenario's, gaps in the rule-based model can be found. Some might be possible to tackle by extending the database with more strategies or criteria. When this is not possible, ships will have to communicate to come-up with a solution, this will not be part of this research.

This part will also include the design of the tool which is used to evaluate the model and test new strategies to improve navigational safety. The tool will include different modules to make sure a realistic simulation can be done. These modules contain for example a manoeuvring model and communication protocol.

5 | Database for identification

Different situations and scenarios can be identified. This identification is used to develop a decision tree. Using the OODA-loop different steps for decision making can be separated . The first step is to observe the situation, this is done by classification based on the path of nearby vessels. The next step is to orient, thus to determine the possible strategies. Next step is to decide which strategy is the right one, by evaluating criteria. Finally you must act on this decision. In this chapter the first steps classification the situation, based on observations is discussed. Followed by the steps taken in the orientation phase to form strategies.

ref to ooda-loop

5.1 Situation identification

Based on the observations different situations can be classified into four types, the different types are described below:

- *Passing*. Ships do get close, but the paths are not crossing
- *Crossing*. Paths of ships are crossing
- *Merge*. Two ships from different directions, heading in the same direction, strategy might lead in many cases to a take-over.
- *Take-over* Two ships following the same path with different speeds.

It depends on the type of waterway which situation is likely. To determine this, a classification of paths is used. To do this systematically, paths can be written as:

[current position, direction]

Combining paths of two ships will describe a situation. Using the system to describe paths. The situations can be written down as:

(path own ship | path other ship).

To classify a situation where two vessels encounter each other, the paths are considered. Key is to determine the angle between those paths. This way it is possible to classify them using table 5.1. The boundaries are based on COLREGs and shown in figure 5.1. .

use colreg boundaries in junction

Own ship	Other ships	Situation
[A,D]	[D,C] [D,B] [D,A] [C,B] [C,A] [B,A] [B,C]	Passing
[A,C]	[C,A] [C,B] [B,A]	Passing
[A,B]	[D,C] [C,D] [B,A]	Passing
[A,C]	[D,B] [D,A] [C,D] [B,D]	Crossing
[A,B]	[D,A] [C,A] [B,D] [B,D]	Crossing
[A,D]	[C,D] [B,D]	Merge
[A,C]	[D,C] [B,C]	Merge
[A,B]	[D,B] [C,B]	Merge
[A,D]	[A,D]	Over-taking
[A,C]	[A,C]	Over-taking
[A,B]	[A,B]	Over-taking

Table 5.1: Standardized paths for situations

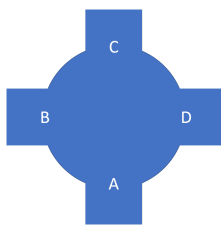

Figure 5.1: Path description

5.2 Strategy orientation

Before criteria can be evaluated, more detailed information is needed. Below different types of information are discussed and their consequences on the strategy.

5.2.1 Type of waterway

To determine which strategies can be chosen. The type of waterway is the first to consider. As this might restrict the area where can be sailed, which influences the possible strategies. For example is it common to over-take ships in open-water on starboard side. While on restricted waterways ships will sail as far as possible to starboard already. This means the ship which is over-taking will have to pass on the port side of the other vessel, at the center of the waterway.

In the next step other static hazards are considered to check if the chosen strategy does not lead to a collision. Or if there are specific regulation frameworks for this waterway. These are however not part of the first iteration of the decision model, as this will introduce much more complexity, without improving the result in most cases.

add definition of static hazard and more examples, to make link to evaluation tool and tags

5.2.2 Actors

The second step is the identification of the dynamic objects. This are all objects which are moving. Most important are off course other ships which do come close. But in future developments of the decision model, objects which are not under any control of a human should be considered, such as floating containers.

To predict the path, first the general information about the object should be acquired. Such as manoeuvrability, speed, course, type of object, under control, etc. Thereby might it be possible in future developments to take into account the human factor to improve the path prediction. This could be based on the experience of the crew, availability of a pilot or if the vessel is completely unmanned.

also describe the rules, which might be based on signs

5.2.3 Scenarios

Using the information on type of waterway, location and actors, the scenario can be identified. Based on the scenarios, can be determined which rules do apply and what their implications are on the possible strategies. The same goes for the estimated path of dynamic objects. This might also narrow down the possible strategies.

Using the above mentioned information in the decision model, the strategies can be narrowed down. This can be used to simplify the decision tree and select the right criteria to evaluate.

add more examples to describe consequence on strategy

add more examples to describe consequence on strat-

6 Definition of criteria

To determine which strategy works best, different criteria are evaluated. Most of these criteria are already calculated by the current systems, such as ECDIS and ARPA. However do they use linearized algorithms, which do not predict the closest points of approach and crossing distance correctly while turning. The current and proposed algorithm are discussed below. This is followed by a section on the criteria which can't be calculated.

6.1 Calculations based on current systems

Within ARPA and ECDIS the criteria are often already calculated, using linearized algorithms. Below these calculations are discussed for the Closest point of approach (CPA) and crossing position.

6.1.1 CPA

Code snippet :

convert to nice latex math

```
xA = shipA.location[0]
yA = shipA.location[1]
VA = shipA.speed
UxA = math.sin(shipA.course)
UyA = math.cos(shipA.course)

xB = shipB.location[0]
yB = shipB.location[1]
VB = shipB.speed
UxB = math.sin(shipB.course)
UyB = math.cos(shipB.course)

 if (shipB.course == shipA.course) and (shipB.speed == shipA.speed):
 distance = math.sqrt( (xB-xA)**2 + (yB - yA) ** 2)
 print('%s and %s parallel: %d meter apart' % (shipA.name, shipB.name, distance
 return [distance, 0]

 distance = math.sqrt((
yA * VA * UxA - VA * yB * UxA - yA * VB * UxB + VB * UxB * yB - xA * VA * UyA
UxA ** 2 * VA ** 2 - 2 * UxA * UxB * VA * VB + UxB ** 2 * VB ** 2 + UyA ** 2 *
 time_s = (((-xA + xB) * UxA - UyA * (yA - yB)) * VA + VB * ((xA - xB) * UxB +
 (UxA ** 2 + UyA ** 2) * VA ** 2 - 2 * VB * (UxA * UxB + UyA * UyB) * VA + VB *
```

6.1.2 Crossing

Code snippet :

convert to nice latex math

```
 locA = np.transpose(np.matrix(shipA.location))
 locB = np.transpose(np.matrix(shipB.location))
```

```
p = locA - locB

UA = np.array([[math.sin(shipA.course)], [math.cos(shipA.course)]])
UB = np.array([[math.sin(shipB.course)], [math.cos(shipB.course)]])

d = np.concatenate((UB, -UA), axis=1)
n = np.linalg.inv(d) * p

crossing = locB + n[0, 0] * UB
relativeSpeed = n[1, 0] / n[0, 0]
```

6.2 Proposed algorithm based on planned path

Using the planned path of the vessel, better estimations can be made for the closest point of approach and crossing distance. As this planned path is not available for other ships, without introducing new systems, an estimation is made for the likely path. Which first uses a first order change, based on rate of turn and course. This can be extended with a combination of expected location, using the probability that another ship is choosing a specific strategy.

6.2.1 CPA

1) check if something changed since last calculation -¿ no check out -¿ yes to step 2

2) use waypoints to plan x minutes ahead

3)

Disadvantage: heavier computation and less accuracy due to numerical solve

6.2.2 Crossing distance

6.2.3 Passing distance

6.3 Conditional criteria

6.3.1 COLREGs

How is the path based solely based on COLREGs, without taking into account other ships

use this `https://www.myseatime.com/blog/detail/8-colreg-rules-every-navigating-officer-must`

6.3.2 Bold movement

Combine paths to ensure bold movements

7 | Analysis of scenarios

Example scenarios will be discussed in this chapter. This is done to determine the relevance of criteria in different situations and scenarios. The same steps as described in the previous chapters will be taken to determine the right strategy. Situation sketches are used to support the descriptions. The results will be a list of tags for the specific scenarios, which can be used to identify a situation. These tags can than be linked to the different criteria.

7.1 Entering Maasgeul towards North Sea, Rotterdam

The first scenario which will be analysed, is from the viewpoint of a crude oil tanker, which will leave the port of Rotterdam. To enter the traffic lane towards the Maasgeul, it has to cross the path of another vessel coming from port-side. While taking another ship from starboard into account, which is already heading towards the Maasgeul.

The decisions which have to be taken are to change course and/or speed. This must be done multiple times. Different snapshots are taken throughout, including information on criteria which the crew uses to make their decisions. This example case is made up, but is based on real situations as described by pilots and AIS-recordings. First a description of the situation is given, which is the starting point of this example. The aim of this description is to enable the reader to understand the situation. Next relevant rules are discussed which should be taken into account when deciding on the strategy. Followed by the different snapshots, which will give insight in the decision making process and relevant criteria. This is concluded with a calculations for the relevant criteria.

7.1.1 Situation description

The location of the situation is the junction between the Beerkanaal, Maasgeul, Nieuwe Waterweg and Callandkanaal. A map with more details is shown in figure 7.1. Quays restrict the possible paths ships can sail to avoid each other, there is however no traffic separation scheme. In this example case there will be three vessels involved.

- GULF VALOUR. 249 meter crude oil tanker. Coming from the Yangtzekanaal, heading to the Maasgeul, via the Beerkanaal. Just rounding the pier of 8e Petroleumhaven with 7.8 knots.
- ASTRORUNNER. 142 meter container ship. Coming from the Maasgeul with 13.4 knots heading towards the Calandkanaal.
- ANGLIA SEAWAYS. 142 meter ro-ro cargo carrier. Leaving Rotterdam via Nieuwe Waterweg towards the North-Sea with 10.3 knots.

All ships have licensed pilots on board, thereby do traffic controllers monitor the traffic and might give directions.

In order to classify a situation, tags are used. Example tags for this situation are: *junction, harbour, restricted waterways, multiple vessels, traffic controller*

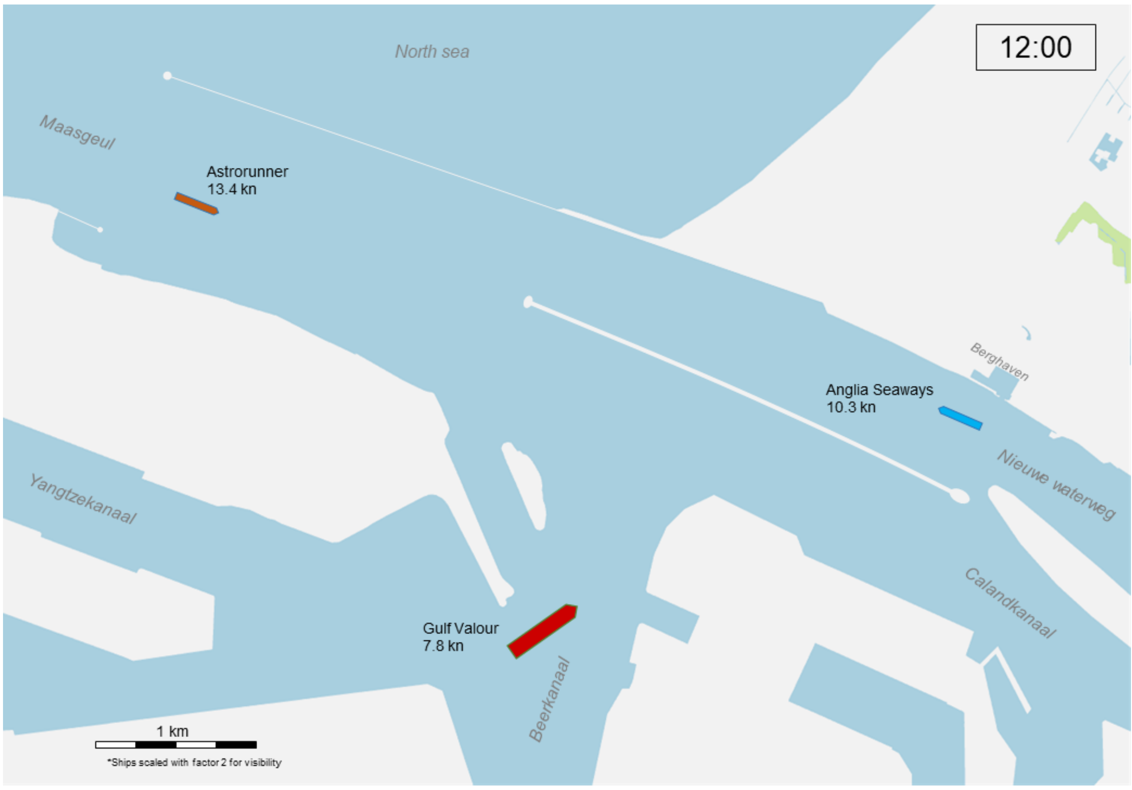

Figure 7.1: Situation sketch 12:00, with area which can be observed by Gulf Valour

7.1.2 Relevant COLREGs

The rules relevant for the situation are discussed, these should be taken into account during the decision making process, ordered in a chronological manner, on the moment it becomes relevant.

Rule 7a: Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt such risk shall be deemed to exist.
This is particularly relevant in this case, as both ships can't be observed by the Gulf Valour by sight or radar at the start, due to port terminals and landmasses.

Rule 19d: A vessel which detects by radar alone the presence of another vessel shall determine if a close-quarters situation is developing and/or risk of collision exists. If so, she shall take avoiding action in ample time, provided that when such action consists of an alteration of course, so far as possible the following shall be avoided:
(i). an alteration of course to port for a vessel forward of the beam, other than for a vessel being overtaken;
(ii). an alteration of course towards a vessel abeam or abaft the beam.
Determining the 'ample time' for different scenarios is the purpose of this research.

Rule 9a: A vessel proceeding along the course of a narrow channel or fairway shall keep as near to the outer limit of the channel or fairway which lies on her starboard side as is safe and practicable.
This might limit the options to avoid a collision, or an exception should be made and com-

municated.

Rule 15: When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel.
It should be determined if the Gulf Valour indeed crosses the Astrorunner in a way, such that this rule applies. It might also be that the Beerkanaal is ranked lower and therefore not really a crossing.

Rule 13c: When a vessel is in any doubt as to whether she is overtaking another, she shall assume that this is the case and act accordingly.
This is mostly relevant when the Gulf Valour comes close to the Anglia Seaways.

7.1.3 Snapshots

To get insight into the decision making process, the first step is to know the situational awareness at different moments in the process. Snapshots are taken from these moments. Giving a summary of the information based on observations and communication. This is used to validate or form strategies and eventually take decisions. Thereby is discussed which criteria are most important and example tags are used to identify the situations.

Communication, Observations, Strategy based on current information, Key criteria

12:00 Start

The traffic controller has radar images of the whole harbour. He uses them to inform all ships about the position and intention of other ships. In this case the Gulf Valour is told there are two other ships. One at the Nieuwe Waterweg heading for the Maasgeul and one at the Maasgeul heading for the Calandkanaal.

The crew at the Gulf Valour sees both vessels on the ECDIS. However is not sure where the ships are exactly, as was mentioned in section 1.3, is the ECDIS not reliable enough. Due to the height of the bridge, it is possible to look over the land a bit, to make an estimation of the position of the other vessels. The ARPA has however too much noise to make the desired calculations.

Currently there is not enough information available to decide which strategy works best. There are no hazards nearby, thus the planned path will be followed. Where the Gulf Valour will make the turn into the Beerkanaal, which will reduce the speed.

Tags: missing information, restricted waterways, multiple vessels, turning

12:03 Ships are visible by sight

To avoid an overload of the communication channels, the communication between ships is kept to a minimum. The most important communication comes from the traffic controller. As the situation did not change significantly, no updates are given.

Both vessels are now also visible on the ARPA and by sight. A closest point of approach is calculated, however this is based on the current heading and speed. As the Gulf Valour is still turning, this information is not of any use. Based on the speed of both vessels, it is possible though to make an estimation where the closest point of approach will occur.

Based on this estimation, a strategy can be chosen. The first choice which should be made is if a thight or wider turn is made through the Beerkanaal. As COLREGs prescribe to keep starboard, and thus a wider turn. Might it be more convenient to end in the middle or even at port side, by making the turn more tight. As there is no traffic coming into the Beerkanaal. But will make it more easy for the Gulf Valour to pass behind the Astrorunner, considering the Gulf Valour will slow down due to the tighter turn. To determine the right strategy, several key criteria are relevant. The first to consider is the moment both ships enter the crossing, relative to each other. The Gulf Valour can influence this by reducing the speed. This will also influence the path taken during the long turn trough the Beerkanaal. If it is better to make a tight turn on port side, or make it wider to end at starboard side of the Beerkanaal. In this case both enter at a similar time, therefor is chosen to have contact with traffic control. They decide to reduce speed a little bit more, by reducing engine speed and making a tight corner.

Tags: restricted waterways, junction, crossing, turning

12:06 Crossing with Astrorunner

At this point the strategy determined at the previous snapshot is executed. Thus the Gulf Valour passes the Astrorunner first startboard-starboard, and crossing the path at stern side. This means they deviated from the standard COLREGs, but with consent of the traffic controllers.

As the Gulf Valour passes at the stern side, it is easy to have a low rate of turn while crossing. This means a good estimation on relative speed to the Anglia Seaways can already be made by sight and via the ARPA.

add screenshot of simulation

Thereby should be considered which speed the Gulf Valour has to travel according to the schedule, which is higher than the current speed of the Anglia Seaways. This means the Gulf Valour has to act like it is overtaking the Anglia Seaways, while also entering the Maasgeul shipping lane. They have to move to starboard side of this shipping lane, to avoid head-on-head colissions with oncoming future traffic, which is not part of this example. Thus the final strategy is to go to the planned speed of 16.2 knots. While sailing in the centre of the shipping lane, leaving enough room to have the Anglia Seaways between the Gulf Valour and the Pier.

Tags: restricted waterways, junction, traffic-lane, crossing, over-taking, turning

12:11 Under control

After crossing behind the Astrorunner the path is continued to the middle of the Maasgeul. To ensure a safe overtaking manoeuvrer around the Anglia Seaways. While overtaking the situation is under control and the Gulf Valour is underway to its next destination, without having the risk for close encounters. A few miles further out the pilot will leave and contact with traffic control is not necessary anymore.

Tags: shipping-lane, over-taking

7.1.4 Criteria check

At every step, several criteria determine the strategy. At the different snapshot moments these criteria are calculated, in order to validate them. The results are shown in table . make table

7.2 Second scenario

discuss another scenario

8 | Decision-model

Use OODA loop van John Boyd, also add something on this in previous chapters.
using the database a model is formed, describe a bit on the rules which will be used.

9 | Development of testing environment

A tool is developed in which can be tested how well decision model works.

9.1 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 money, time and effort, as it is harder to control. Small scale testing will introduce many unknown factors. Therefore is chosen to build an application in which models can be tested. The development will be based on the principles of 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. [Agile Manifesto(2001)]

9.1.1 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.

9.1.2 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. These can be split between users and objects. 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.

9.1.3 User interactions

What should be done in the different modules

9.1.4 Minimum viable product

Considering the above mentioned requirements and user stories. Not everything is within the scope, and thus shouldn't be developed and implemented. Examples of possible features which are not implemented are: ... There must also be considered that several assumptions are made to create a system which works in a practical manner, as not al input data is available or calculations might be very hard and slow down the simulation too much. The assumptions made are: ...

Thereby should be kept in mind that the acceptance criteria for the application is: The ability to insert a model for decision making for a ship, which depends on information collected from other ships closeby, its own ship characteristics and the environment it acts in.

Extent the acceptance criteria for the full application

9.2 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

9.3 Probability index

what should the polygons show

9.4 Routeplanner

Including the usage of waypoints with weights

9.5 Estimation of characteristics

Deadweight to displacement for example

9.6 Application design

Building and verification including description of the architecture. Model-view-controller architecture, for easy modification as there are less dependencies between modules.

9.6.1 Design patterns

Push-pull listener

9.6.2 Model and classes

Use list from excel, make simple drawing how they link an talk to each other. Based on model-view-controller.

9.6.3 Methods

Full list in appendix XXX, describe important methods and how design patterns are used. Push-pull for example

9.6.4 User interface

Some screenshots of the application with a description what can be controlled and seen. Implementation of models is not relevant yet.

10 | Evaluation decision model

10.1 Verification

10.1.1 Test-scenarios

10.1.2 Result of testing

Does the rule-based model tackle the challenges given to it by us

10.2 Validation

Get an expert review to compare it to reality, the strategies and criteria

11 | Lessons learned

Summarize results of verification and validation and if it can be used in the next step. Thereby also explaining which strategies could be communicated to pilots, seafarers and traffic controllers. To make shipping safer. But on the other hand also show where it lacks support.

11.1 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.

11.2 Result

The model developed in this part will start with a sensory information on a situation, it will classify this situation and make a decision based on the evaluation of criteria. The result is an advise to execute a specific strategy, or if the model can't evaluate criteria sufficiently a subset of possible strategies and the remark it needs more information to narrow it down further.

Part III

Interface to enable teamwork between manned and unmanned ships

In the previous part a decision model is described which uses only criteria which do not require communication for an unimpeded voyage. There are however cases in which the decision model can't determine the right strategy. This is often the case due to missing information, or a lack of understanding about the intentions of other vessels. With manned ships verbal communication is used get the missing information, or discuss a strategy with other ships. To have unmanned vessel sail between manned vessel, an interface is needed.

Using the situated Cognitive Engineering (sCE) method, this interface can be developed using an iterative process where a requirement baseline is continuously refined by reviews and prototype evaluations. How to apply sCE is described by Neerincx and Linderberg [Neerincx and Linderberg(2012].

First step is to create a foundation. This discusses the problem to be solved, existing knowledge to solve the problem and the envisioned technology. This together forms the system design specification. Which describes the solution in the form of a system design. This design is finally evaluated.

12 | Foundation

The foundation segment in the sCE methodology describes the design rationale in terms of (a) operational demands, (b) relevant human factors knowledge, and (c) envisioned technologies. Together, these three constituents describe (1) the problem to be solved, (2) the existing knowledge on ways to solve the problem, and (3) the technology needed to implement that solution.

12.1 Operational demands

The operational demands describe the current practice as it is, i.e. without the envisioned technology. For the operational demands, the sCE method prescribes as main components the stakeholders and their characteristics, and the problem description and analysis thereof.

12.1.1 Problem scenario

Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) have been developed long before bridge-to-bridge voice communications became available. They are supposed to be unambigious. It is the responsibility of all bridge watch keepers to know how to apply them instinctively, on the basis of observation primarily by sight and radar. They work effectively when ships in an interaction obey them; they also specifically address circumstances where one ship does not.

However, as shown in the previous parts, are COLREGs not always sufficient to decide on the strategy. For example due to missing information. In those cases the VHF radio can be used for verbal bridge-to-bridge communication. Leading here is the Standard of Maritime Communication Phrases (SMCP). The primary task of this protocol is to diminish misunderstanding in safety related verbal communications. Beside this verbal communication, non-verbal communication might be used, such as light signals, sound signals and semaphore signing.

These different ways for communication are not developed to be used by unmanned vessels. On the other hand, is it not feasible to require all manned vessel to install new systems for communication, before introducing unmanned vessels.

When using the current systems in a way they are not designed for. This might result in information overload of the crew and communication channels. Resulting in misunderstanding and problems with communication. As the VHF can only be used in one way. As it is a receiver or a transmitter, but can't be both at the same time.

12.1.2 Problem analysis

To avoid misunderstanding which could result in hazardous situations. It is important that manned and unmanned vessels are able to communicate. To solve this problem, a more extensive analysis is made. Describing the values of the stakeholders, other actors, and related problems.

Stakeholders

The focus of this research will be on bridge-to-bridge communication. This means the most important stakeholders are the bridges of the manned and unmanned vessels.

- *Officer of watch*. He is the responsible person. He might work together with a helmsman and a lookout. He has to ensure a proper functioning of all available systems. Thereby does he discuss with other crew members if there are any unusual activities. He is responsible to follow a proper navigation plan, while having his own safe passage plan, to avoid collisions. He will use sight, ARPA and ECDIS. Thereby is he aware of the ship's speed, turning circle and other handling characteristics to decide on the right strategy. He will monitor the VHF radio all the time while underway to assist in emergencies if necessary, to hear Coast Guard alerts for weather and hazards or restrictions to navigation, and to hear another vessel hailing you.

  He wants to avoid information overload, while being aware of the situation. This is only possible when he stays concentrated, to acquire this, the tasks must be challenging and he needs to have a form of autonomy.

- *Helmsman and lookout*. Both monitor the situation and execute commands from the officer of watch. They also want to avoid information overload.
- *Crew and pilots on nearby vessels*. They might want to know the intentions of other vessels to base their strategy on. However do not want to receive all discussions. As this will result in an information overload.

Other possible actors

- The agent controlling the unmanned vessel.
- Vessel traffic controllers.
- Crew on vessels which are not traveling.
- Crew which are in distress and require assistance.
- Shipowners of unmanned vessels, monitoring vessel from other location.

is dit een actor?

Information extraction from problem scenario

- Different actors are afraid of information overload.
- Officer of watch is afraid to lose situational awareness.
- Officer of watch is afraid to lose autonomy.
- Current systems not designed to be used by unmanned vessels.
- Manned ships want to ask for support or information.
- Unmanned ships want to ask for support or information.

Goals

The main goal is to ensure reliable sharing of information, without the risk for information overload or misunderstanding.

Problem breakdown

This means that manned vessels should be updated only when requested or in case of an unusual activity which could affect their strategy. And manned vessel should be aware when unmanned vessels desire more information to decide on the right strategy.

Possible situations when communication is needed

- No visual
- Bad weather
- Unreliable information from AIS

Problems that might also be adressed

Communication with traffic controllers. If it is also not feasible for them to have a new system to communicate and direct unmanned ships.

Infeasible solutions

The easiest solution for unmanned ships would be to just install a new system. However this is not feasible, as this would mean that all ships which could encounter an unmanned ship will have to install this too. It might be possible to make it obligatory via regulations, this will however cost a lot of time and money. Making the introduction of unmanned ships less likely. This is also the reason to use a Non-visual User Interaction (no-UI), as a GUI will require new screens or changes to the ECDIS which are only possible when regulations are changed.

12.2 Human factors

When designing technology, there are two driving questions that need to be well-thought out: (1) What tasks and/or values is the user trying to accomplish and how can the technology support the user in doing so?, and (2) How can the technology be designed such that the user is able to work with the technology?

The Human Factors segment of the sCE method describes the available relevant knowledge about, for instance, human cognition, performance, task support, learning, human-machine interaction, ergonomics, etc. Note that we emphasize that this knowledge should be relevant for the problem and its design solution: the knowledge described here should lead to a better understanding of either (1) or (2).

The three constituents important to the human factors analysis are: (a) the human factors knowledge, (b) measures, and (c) interaction design patterns.

Human factor knowledge

Human factors knowledge describes available knowledge coming from previous research about how to solve the problems that have been identified in the problem analysis.

- Which information is needed to have situational awareness? [Rothblum et al.(2002] [Breda and Passenier(1999] [Prison et al.(2013] [Hodgetts et al.(2015] [Porathe et al.(2014]
- When does information overload occur? [Arimura et al.(2001] [Neerincx(2008)] [Schutter(2016)] [Porathe et al.(2014]
- What is more effective to ensure a feeling of autonomy? [Feys et al.(2016]
- How is information perceived if it is being pushed or pulled? Thus listen to radio with continious information (repeating), or only send message when asked for
- What are the expectations of a human from an unmanned ship?
- Do people trust automated systems in emergency situations? [Neerincx(2008)] [Walliser(2011)]
- Is there an uncanny valley for chatbots?
- ...

link papers to questions and answer

Human factor measures

Measures describe how to operationalize the quality of the intended behavior or performance, i.e. how well is a user working with the design able to reach his/her objectives and what is the quality of the collaboration between the human worker and the technology?

- Is the system used correctly?
- Does the interface give reliable information?
- Will it solve the problem of missing information?
- ...

Interaction design patterns

Interaction design patterns (IDPs) focus on the human-computer interaction, such as usable interface design and control options. IDPs offer generic solutions to recurring HCI design problems that have been proven to be effective. IDPs are often made available in repositories.

- Auditory alarms
- Distress, urgency and safety signals
- Usage of message markers
- Chatbot

- Natural language variations on SMCP
- Light signals
- Sound signals
- ...

12.3 Envisioned technology

The envisioned technology describes the available options of using existing technology and/or the need to develop novel technology in order to come to a system solution. The sCE method asks designers to specify what devices (hardware) and software could be used in the system design. In addition, for each type of technology, an argument should be provided as to why this technology might be of use and what the possible downsides might be of that particular type of technology.

Using only existing systems to develop a Non-visual User Interaction (no-UI). These existing systems are described in chapter 1:

- Visible signals
  - Positions
  - Change of heading
  - Light signals
  - Flags or symbols
- Availability on VHF
- Exchange of information via AIS
- Horn

Thereby is it easier to learn when its based on known protocols, such as Standard of Maritime Communication Phrases (SMCP) and COLREGs.

13 | System design specification

The system design specification describes the solution to the problem in the form of a system design that makes use of the identified relevant human factors knowledge and the envisioned technology. The system specification consists of (a) design scenarios, (b) actors and use cases, (c) requirements, (d) claims, and (e) ontology.

13.1 Design scenarios

The sCE method prescribes the specification of design scenarios. Design scenarios are short stories that provide a clear description of how the user will work with the technology thereby enjoying the solution offered to one of the problem scenarios. Together, the problem and design scenarios provide a contextualized view on:

1. The problem the design aims to solve.
2. The people that are currently affected by this problem.
3. The way in which the current system design aims to solve this problem.
4. How people will use the system.

Manned ships are able to understand intentions of unmanned ships, resulting in good situational awareness. In cases they desire more information, they are able to acquire this using current systems. Without the risk for an information overload. Thereby are the additions to existing protocols for those systems easy to understand, as they use the same philosophy as current protocols.

Trust in autonomous ships is formed, as the information is reliable, the interaction is similar to the interaction with other manned ships. This resulted in acceptance of unmanned ships on the general waterways. Where the risk of collisions and perceived risk did not increase.

13.2 Use case

Scenarios are used to create more specific descriptions of step-by-step interactions between the technology and its users (i.e. use cases). Use cases include actors, to specify which stakeholders/agents are interacting with each other in a given action sequence (use case).

NB: Use cases do not specify the way in which the technology enables the described interactions. For example, the interactions may take place through voice commands and audio, but could also be text-based, be instantiated with the use a drop-down menu, or even by a human operator sitting on the other side of the application, listening and responding to the events taking place. No assumptions are made about the level of automation or the current capabilities of the technology in mind. A use case simply describes the behaviour of the system, regardless of the technology required to produce that behaviour. Because the sCE method describes an iterative process of specifying the system's design, at later stages some behaviours may prove to be infeasible or not viable. This may result in alternative use cases that may be better aligned with the available technology. But it may also be the case that one ends up with a slightly different version of the technology that in fact is able to produce the ideal behaviour described in the original use case. The main goal of iteratively refining the system specification is to gather all the alternative design solutions, compare them in systematic evaluations, and converge to one design solution that is effective, reliable, affordable, etc

The use cases provide a detailed description of the interactions between the technology and its user. Use cases make the design scenario more concrete by describing exactly how the technology makes sure that the elderly is safe and taken care of. Use cases are informed by human factors theories (described in the system's foundation).

13.3 Functional requirements

In the sCE method, use cases are used to derive functional requirements, i.e. specific functionalities the technology should provide to its user.

13.4 Claim

The sCE method prescribes a strong link between the system's functional requirements, the system's objectives, and the hypotheses to be tested during system evaluations. This is accomplished by annotating all functional requirements with their underlying objectives (called claims).

This explicit linking of requirements to claims enables designers to formulate hypotheses that need to be tested in system evaluations to justify the adoption of the functional requirement. If the claim cannot be proven to be valid through system evaluations, the designers need to refine their system design, for instance, by trying to improve the functionality, replacing the functionality with a different one, or dropping the functionality and the claim altogether (i.e. by deciding that the objective is not reachable at this point). Either way, there is no use of including a functionality that does not achieve its underlying claims.

13.5 Ontology

Lastly, the sCE method prescribes the construction of an ontology, i.e. a vocabulary describing a common language to be used throughout the system specification to avoid miscommunication, misunderstanding, and inconsistencies. Furthermore, the ontology can serve as the basis for the technology's data structure. By specifying important concepts in the ontology and also choosing to use only one word instead of various ambiguous synonyms, communication becomes clearer and misunderstandings can be reduced to a minimum. The terms specified in the ontology are consistently used throughout the entire project. Running

14 | Design evaluation

The last part of the sCE method is the design evaluation. The design evaluation aims to test and validate the system's design, or to discriminate between multiple design options, such that the current design can be improved upon in incremental development cycles. The sCE method describes three parts that are relevant with respect to the system evaluation: (1) the artefact, (2) the evaluation method, and (3) the evaluation results.

14.1 Artefact

The artefact is an implementation or prototype that incorporates a given set of requirements, interaction design patterns, and technological means.

14.2 Evaluation method

The evaluation method can take many forms, such as a human-in-the-loop study, a use-case-based simulation, or an expert review.

14.3 Evaluation results

The evaluation results describe the outcomes of the test. Because of the iterative and rapid research cycles, the evaluation does not necessarily include all requirements/claims/use cases available in the system specification. Oftentimes the evaluation investigates a subset of the system specification. Therefore, it is often useful to also specify what claims were tested, with the use of what evaluation method, and what artefact was used during the evaluation (i.e. which requirements, technology, interaction design patterns were included in the artefact).

Part IV

Wrap-up

15 | Results

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

16 | Conclusion

16.1 Answers to research questions

16.2 Recommendations for future research

Part V

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

Steps to be taken

The plans mentioned in section **??** 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.

Specific step on road map 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 behavior of other vessels. As this can be used to improve the warning system within current ECDIS systems.

refer to timeline infor-graphic in pre-vious chapter

Research questions

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

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 nature of traffic situations, this is not always possible. Showing possible intentions of other vessels to the crew will enable them to acquire 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 can manoeuvrer easily. 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 radio communication. This will lead to an unimpeded voyage, as critical situations can be avoided. 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?"*

Computer Science

The communication on intentions of other vessels 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 channels. The current system is certainly not flawless, as AIS is not always used correctly and in some situations COLREGs require 'good seamanship'. 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?"*

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 scenarios and strategies will eventually be validated together with seafarers.

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