MSc Thesis

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Ingmar Wever (4161041)
August 20, 2018

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MSc Thesis

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August 20, 2018

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Abstract

Glossary

list of used symbols

Abbreviations

AIS Automatic Identification System

AMS Alarm Management System

ARPA Automatic Radar Plotting Aid

BNWAS Bridge Navigational Watch Alarm System

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

CFD Computational Fluid Dynamics

COLREGs Convention on the International Regulations for Preventing Collisions at Sea

CPA Closest point of approach

DOF Degrees of freedom

DP Dynamic Positioning

ECDIS Electronic Chart Display Information System

ENC Electronic Navigational Chart

GNSS Global Navigation Satellite System

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

OoW Officer of Watch

sCE situated Cognitive Engineering

SMCP Standard Maritime Communication Phrases

SMNV Standard Marine Navigational Vocabulary

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.

hoe ga ik ervoor zorgen dat het schip tijdig anticipeert, en weet ik of ik in de problemen zit omdat het niet meer mogelijk is om tijdig te communiceren

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 manoeuvrability characteristics influence the domain for decision making, to ensure that the chosen strategy will result in a safe minimal distance between vessels?*

> *Are existing technologies for communication sufficient to ensure that manned and unmanned vessels can operate side by side safely?*

Report structure

Within the project, several steps will be taken. At first more context is given on the current state of the maritime industry in respect to autonomous sailing and ways of communication. Thereby mentioning how the knowledge developed in this research, will help to tackle challenges. 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.

link structure to chapters

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. Nowadays communication has become very important to ensure the safety of all ships. Where communication can be all forms of sharing information. 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 led to new ways for communication, which subsequently led to safer operation. 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 at the right time. The current situation of the maritime is assessed together with a summary of likely new technologies related to navigational safety.

First the technologies which are currently used to ensure safe navigation of vessels is discussed. This is followed by a description of accidents which occurred, giving insight in the mistakes made and how this can be avoided with improved systems. Which projects on these new systems and unmanned ships are discussed in chapter 4. The development of autonomous and unmanned ships are discussed, as these have advantages when it comes to safety. The last chapter of this part will describe a model to discusses the knowledge which will autonomous and unmanned ships will be safer.

1 | Decision model

To gain more insight in the steps which should be taken towards unmanned and autonomous shipping. Its important to first gain more knowledge on the decision process. This process is modeled. This model is partly based on the John Boyd's OODA loop [Boyd(1987)]. This model is used in many similar cases, but mostly in military command and control situations [Arciszewski et al.(2009)] [Kalloniatis et al.(2017)].

The steps within this model are to observe, orient, decide and act. The new model describes how this applies to choosing the right strategy in common maritime encounters. In figure 1.1 a visual of the decision model is shown. The first step describes what can be observed, to form a mental model. The next step is to orient, where the situation and hazards are identified based on different criteria. This will result in a set of strategies, these will be evaluated using different criteria, resulting in a decision. After this decision, an action can be executed. This chapter will discuss these phases already in more detail. 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. These other subjects will be discussed in the other parts of this thesis.

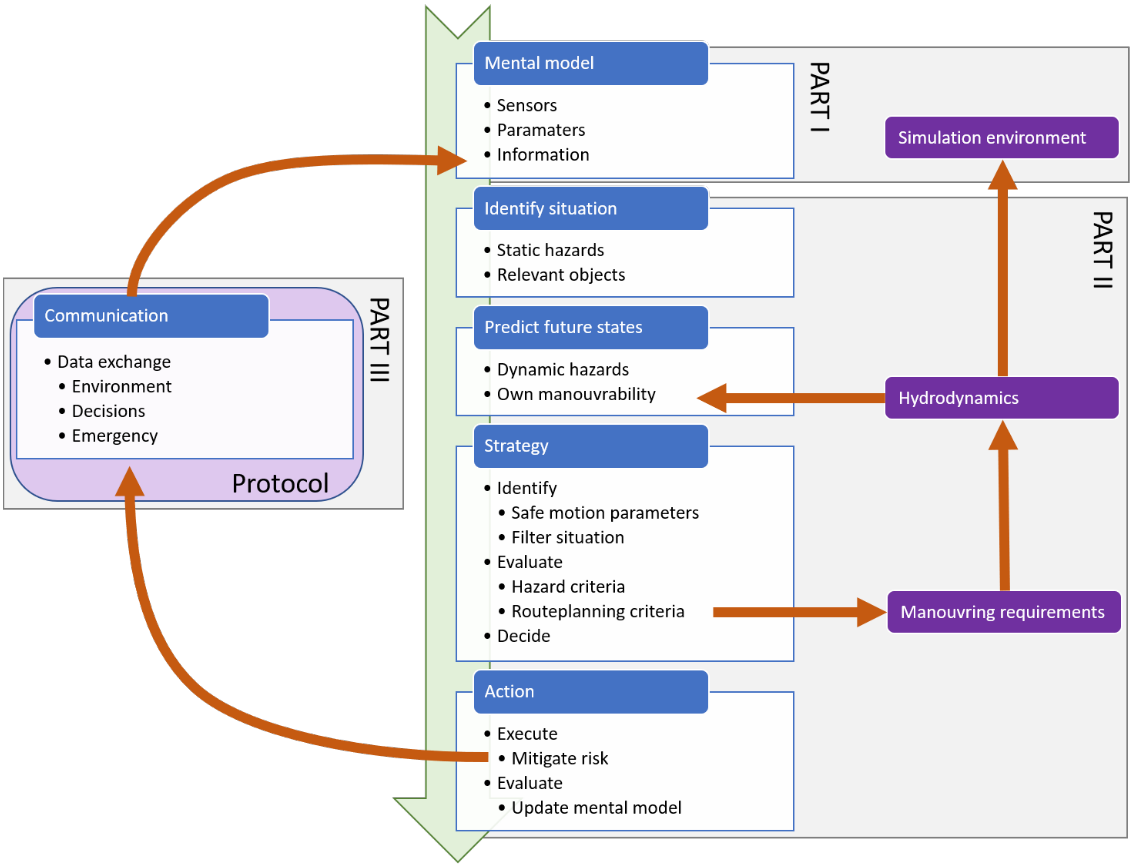


Figure 1.1: Abstract model

1.1 Mental model

1.2 Orientation phase

1.2.1 Identify situation

1.2.2 Predict future states

1.3 Decision making

1.3.1 Strategy

1.4 Communication

2 | Current systems for safe navigation

Before developing new systems and procedures to improve safety, the first step is to know what is currently available. Thereby should be considered how different types of information can be supplied. Nowadays decisions on navigation are taken from the bridge. Thus all information must be available there. In this chapter these elements will first be discussed, how they are in theory. This is followed by a discussion on the differences between this theory and practice. Which results in a conclusion on relevant systems for the communication between manned and unmanned ships.

2.1 Bridge system elements

To gain insight in a structured way, the bridge is split into four elements as described by DNV-GL. The human operator, procedures, technical system and the human-machine interface [DNV GL(2011)], as shown in figure 2.1. This section describes every element in more detail.

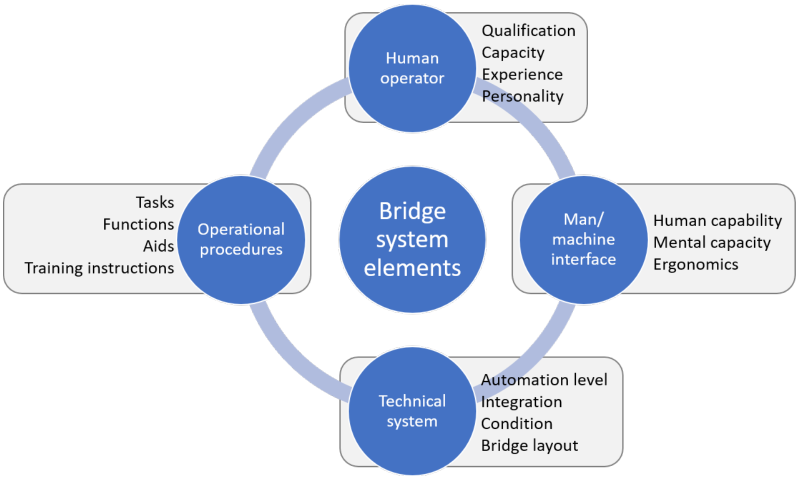


Figure 2.1: Bridge system elements

2.1.1 Technical system

The first element which will be discussed are the instruments and equipment at the bridge, the technical system. The different classification societies prescribe the equipment which is obligated to have at the bridge. These are based on the regulations for navigational equipment on board of ships from the International Convention for the Safety of Life at Sea (SOLAS), a modern ship should at least have:

- Magnetic compass
- Gyro compass
- ECDIS
- Transmitting heading device
- Automatic Identification System (AIS)
- Receiver for Global Navigation Satellite System (GNSS)
- Internal communication system
- Bridge Navigational Watch Alarm System (BNWAS)
- Telephone for external communication

- Radar
- Radar beacon
- Daylight signaling lamp
- Speed and distance measuring device
- Echo sounding device
- Rudder, propeller, thrust, pitch and operational mode indicators
- Rate of turn indicator

Based on this list, DNV-GL demands at least the following equipment shall be installed at the bridge [DNV GL(2011)]. The equipment may have different roles. To control the ship, to present information, or to communicate:

- Propulsion control
- Emergency stop machinery
- Manual steering device
- Steering mode selector switch
- Heading control
- Window wiper and wash controls
- Control of dimmers for indicators and displays
- Steering gear pumps
- Gyrocompass selector switch
- Navtex receiver
- Automatic Radar Plotting Aid (ARPA)
- Electronic Chart Display Information System (ECDIS)
- Automatic Identification System (AIS) transceiver
- General alarm control
- Very High Frequency radio (VHF) unit
- Whistle and manoeuvring light push buttons
- Internal communication equipment
- Central alert management system

Some of these systems will be highlighted to show the relevance for the development of unmanned vessels, as these systems are currently the most important systems while navigating. Thereby should be considered that more details on underlying procedures are given later in this chapter.

Navigational text Messages (Navtex)

Navtex (Navigational Telex) is an international automated medium frequency direct-printing service for delivery of navigational and meteorological warnings and forecasts, as well as urgent maritime safety information to ships. Navtex was developed to provide a low-cost, simple, and automated means of receiving this information aboard ships at sea within approximately 370 km (200 nautical miles) off shore. Transmissions are typically transmitted from the National Weather Authority, Coast Guard or other navigational authority. The system is an important element in the Global Maritime Distress Safety System (GMDSS). Therefore does SOLAS mandate certain classes of vessels must carry Navtex. Examples of messages which can be received are:

- Navigational warnings
- Meteorological warnings
- Meteorological forecasts
- Search & rescue information
- Piracy information
- AIS messages

The receiver automatically prints the messages. The officer of watch keeps track of the received messages, and anticipates on them when necessary.

Very High Frequency radio (VHF)

Marine VHF radio refers to the radio frequency range between 156 and 174 MHz. In the official language of the International Telecommunication Union the band is called the VHF maritime mobile band. A marine VHF set is a combined transmitter and receiver and only operates on standard, international frequencies known as channels. For example is channel 16 (156.8 MHz) the international calling and distress channel. Transmission power ranges between 1 and 25 watts, giving a maximum range of up to about 60 nautical miles (111 km) between aerials mounted on tall ships and hills, and 5 nautical miles (9 km) between aerials mounted on small boats at sea level (figure 2.2). Frequency modulation (FM) is used, with vertical polarization, meaning that antennas have to be vertical in order to have good reception.

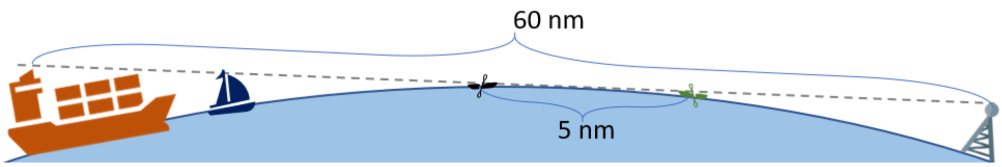


Figure 2.2: Very High Frequency radio (VHF)

Modern-day marine VHF radios offer not only basic transmit and receive capabilities. Permanently mounted marine VHF radios on seagoing vessels are required to have certification of some level of "Digital Selective Calling" (DSC) capability, to allow a distress signal to be sent with a single button press.

Marine VHF mostly uses "simplex" transmission, where communication can only take place in one direction at a time. A transmit button on the set or microphone determines whether it is operating as a transmitter or a receiver. Some channels, however, are "duplex" transmission channels where communication can take place in both directions simultaneously when the equipment on both ends allow it (full duplex), otherwise "semi-duplex" is used. Each duplex channel has two frequency assignments. Duplex channels can be used to place calls on the public telephone system for a fee via a marine operator. When full duplex is used, the call is similar to one using a mobile phone or landlines. When semi-duplex is used, voice is only carried one way at a time and the party on the boat must press the transmit button only when speaking. This facility is still available in some areas, though its use has largely died out with the advent of mobile and satellite phones. Marine VHF radios can also receive weather radio broadcasts, where they are available.

Automatic Radar Plotting Aid (ARPA)

Radars have been playing a vital role in ship navigation for several decades now, assisting in collision avoidance and early detection of obstacles.The history of marine radars goes a long way back to the time of World War II, when radars were introduced and effectively used by war ships for tracking and detection. Radar technology has improved immensely from post-WWII period to the present and the application of computer technology to commercial marine radar sets resulted in the introduction of Automatic Radar Plotting Aids (ARPA). A print-screen of an ARPA systems can be seen in figure 2.3.

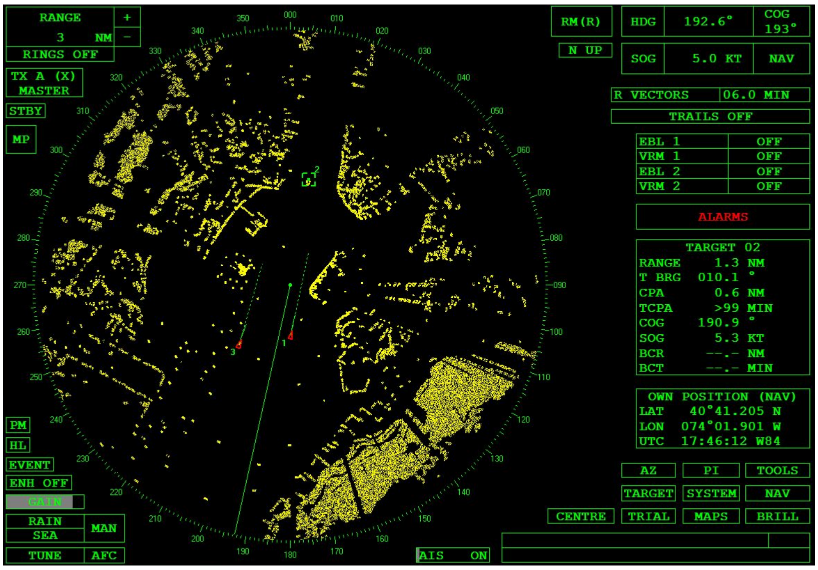


Figure 2.3: Automatic Radar Plotting Aid (ARPA)

Automatic radar plotting aids are essentially utilized to improve the standard of collision avoidance at sea. Primarily designed as anti-collision radar, the ARPA technology removed the chore of plotting targets manually on a reflection plotter or separate plotting aid. The system is able to acquire automatically and constantly monitor number of targets, plot their speeds and courses, present these as vectors on the display screen, updated with each sweep of the antenna, and calculate their closest points of approach to own ship and the time before that will occur.

Electronic Chart Display Information System (ECDIS)

The Electronic Chart Display Information System (ECDIS) is a development in the navigational chart system used in naval vessels and ships. With the use of the Electronic Navigational Chart (ENC) system, it has become easier for a ship's navigating crew to pinpoint locations and attain directions. ECDIS equipment complying with SOLAS requirements can be used as an alternative to paper charts. Besides enhancing navigational safety, ECDIS greatly eases the navigator's workload with its automatic capabilities such as route planning, route monitoring, automatic ETA computation and ENC updating. In addition, ECDIS provides many other sophisticated navigation and safety features, including continuous data recording for later analysis. How the ECDIS is integrated in the bridge can be seen in figure 2.4.

Figure 2.4: Electronic Chart Display Information System (ECDIS) integrated in bridge console

The ECDIS utilises the feature of the Global Positioning System (GPS) to successfully pinpoint the navigational points. It also has to be noted that the ECDIS adheres to the stipulations set by the International Maritime Organisation, and thus it adds to the trustworthiness of the electronic chart system. ECDIS is basically a navigational information system, interfaced with other navigational equipments such as the GPS, Gyro, RADAR, ARPA, Echo Sounder etc.

Automatic Identification System (AIS)

AIS is designed to be capable of providing information about the ship to other ships and to coastal authorities automatically. The SOLAS regulations require AIS to be fitted aboard all ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships by 31 December 2004, this means there are still ships which do not have AIS. Ships fitted with AIS shall maintain AIS in operation at all times except where international agreements, rules or standards provide for the protection of navigational information.

The regulations require the AIS to provide information on ship's identity, type, position, course, speed, navigational status and other safety-related information. Which will be automatically send to appropriately equipped shore stations, others ships and aircrafts. While also being able to receive such information automatically from similarly fitted ships, to monitor and track them. Lastly they should be able to exchange data with shore-based facilities.

Originally the messages were send regularly via a VHF transmitter. The information originates partly from ship's navigational sensors. Other information, such as the vessel name and VHF call sign, is programmed when installing the equipment. Some information must be filled in by hand, such as the status or destination, which is often forgotten. The received information can be displayed on a screen or chart plotter, showing the other vessels' positions in much the same manner as a radar display. Data is transmitted via a tracking system which makes use of a Self-Organized Time Division Multiple Access (SOTDMA).

There are different types of transmitters. Depending on the object it is installed on. This determines what kind of messages can be send and which protocol is used to access AIS slots. Below relevant types are described:

- Class A, the most common type of AIS transceiver for large merchant vessels.
- Class B, AIS for smaller vessels.
- Base station, shored-based AIS transceiver, able to maanage AIS slots.
- Aids to navigation, shore- or buoy based transceiver operating in fixed time-slots. Designed to collect and transmit data related to sea and weather conditions, or forward AIS messages to extend reach.
- Search and rescue transceiver, designed to function as an emergency distress beacon, with high probability of success for transmission.

As mentioned before, there are different types of AIS messages, identification numbers are used to identify the type of message within the NMEA string. The following types of messages are relevant for this research and the development of unmanned ships [US Coast Guard(2018)]:

- Position report, reports navigational information.
- Standard class B equipment position report, less detailed report for vessels using class B transmitters.
- Base station report, used by base stations to indicate presence.
- Static and voyage related data, gives information on a ship and its trip
- Binary addressed message and acknowledgment, an addressed point-to-point message with unspecified binary payload.
- Binary broadcast message, broadcast message with unspecified binary payload.
- Standard Search and Rescue Aircraft Position Report, used by an aircraft (helicopter or airplane) which is involved with search and rescue operation on the sea (i.e. search for and recovery of survivors of an accident at sea).
- Addressed Safety-Related message and response, used to send text messages to a specified vessel.
- Interrogation, used by a base station to get the status of up to 2 other AIS devices.
- Aids-to-navigation report, used by an (AtN) aid to navigation device (buoys, lighthouse, etc.).
- Multiple slot binary message with communications state, used to transmit binary data from one device to another.

2.1.2 Man/machine interface

Previously all information was plotted by hand on navigational charts. With the developments of integrated bridge systems and for example the ECDIS, this is not necessary. This also means that a digital representation of the environment is already being made. Including calculations, relevant for navigational safety. These also give warnings to avoid collisions or represent information received via VHF. This is done in a way which is more easy to interpret by the officer of watch, as for example AIS, ENC and the radar are combined. Examples of the different systems can be found in figure 2.5.

These screens are all integrated in some way into the bridge console. Depending on the size of the vessel, the lay-out may differ. Although, there are also regulations for the placement of systems in SOLAS. Examples of these bridge layouts can be found in figure 2.1.

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.

2.1.3 Human operator

The human operator has two sides, to formal straight forward role as an operator. Which can be described with a list of tasks depending on their function. And the more difficult and unpredictable side of being a human. Which relates to the situational awareness and decision making ability.

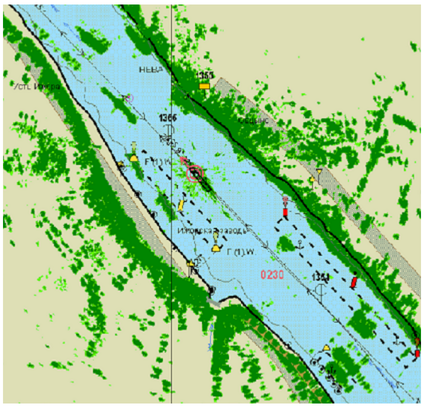
Role as operator

To give more insight into the different roles on board of a merchant's vessel, is the structure shown for officers in figure 2.7. At smaller vessels, roles are combined where possible. The Navy has in some cases even more operational crew members. Apart from the licensed officers who manage the vessel, does the crew also consist of ratings who have hands-on skills within their own domain. [Nedcon(2013)]

For this research the Deck crew is most relevant, as they are in charge of the vessel navigation, watch keeping, maintaining the ship's hull, cargo, gear and accommodation, taking care of the ship's lifesaving and firefighting appliances. The deck department is also the one in charge of receiving, discharging and caring for cargo. According to the vessel's hierarchy, the deck officers are as follows: Master, Chief Officer, Second Officer, Third Officer and Deck Cadet (deck officer to be).

The supreme authority on board a merchant's vessel is the Master or Captain. The entire crew is under his command. He is responsible for the safety, use and maintenance of the vessel and makes sure that every crew member carries out his work accordingly. He is also in charge of the following: payroll, ship's accounting, inventories, custom and immigration regulations, and the ship's documentation. In order to become Master, a seafarer must first have several years of experience as a deck officer and as Chief Officer. According to the vessel's hierarchy, the first deck officer and the head of the deck department after the Master is the Chief Officer. He is in charge of the vessel navigation, watch duties, charging and discharging operations. The Chief Officer also directs all the other officers on deck, creates and posts watch assignments and implements the Master's orders in order to maintain safe operations and maintenance of the vessel. Second Officer or Second Mate is the next in rank after the Chief Mate and is the ship's navigator, focusing on creating the ship's passage plans and keeping charts and publications up to date. Apart from watchkeeping, the Second Officer may also be designated to train the cadets on board or to fulfill the rank of security, safety, environmental or medical officer. The Third Officer or Third Mate is the fourth deck officer in command and is usually the Ship's Safety Officer, responsible for ensuring the good functioning of the fire-fighting equipment and lifesaving appliances. He undertakes bridge watches and learns how to become a Second Officer. A Cadet on board a merchant's vessel receives structured training and experience on board and learns how to become a deck officer.

(a) Separate screens for ECDIS and Radar



(b) Radar overlay

Figure 2.5: Electronic Chart Display Information System (ECDIS)

(a) Alphatron AlphaBridge

(b) DAMEN ASD Tug 2310 (Patriot)

(c) BIBBY WAVEMASTER 1

(d) DAMEN Stan Patrol 5009

Figure 2.6: Various examples of bridge designs

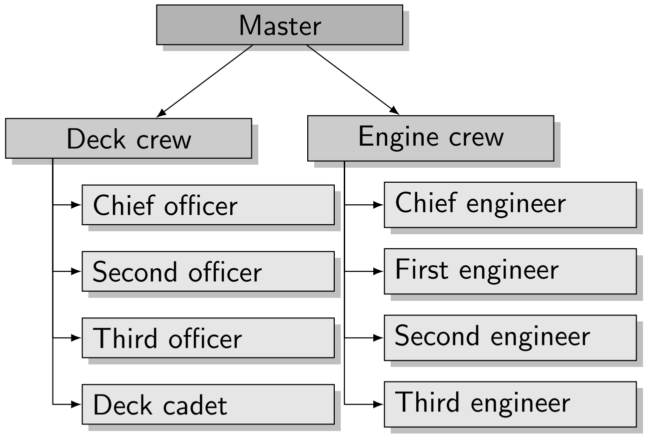


Figure 2.7: Crew structure basic

Apart from the officers, the deck department crew also consists of ratings, such as AB (Able Body Seaman), OS (Ordinary Seaman) and Boatswain. The AB is part of the deck crew and has duties such as: taking watches, steering the vessel, assisting the Officer on watch, mooring and un-mooring the vessel, deck maintenance and cleaning. The AB also secures and un-secures the cargo and carries our deck and accommodation patrols. OS is the crew member whose main duty is to maintain the cleanliness of the whole ship and serves as an assistant for the AB. Being an OS is considered to be an apprenticeship, a period called "sea time" in order to be allowed to take courses and training for AB. Both AB and OS are usually supervised by a Boatswain, who is also a rating, in charge of examining the cargo-handling gear and lifesaving equipment as well. The Boatswain usually holds an AB certificate as well. The structure for the deck department on board merchant vessels is mainly the same on all vessel types. [Nedcon(2013)]

Human factor

At unmanned autonomous vessels the human operator will be replaced by a computer. This means that the duties as described above will be executed by a computer. This automation step has unknown consequences for the ability to observe and decision making. While it has clear advantages when it comes to memory and reduced concentration due to fatigue.

Situational awareness is a model to determine the ability to observe and make decisions. How well humans perform is determined by their (learning) experience [Underwood et al.(2013]. Hereby is important to notice that situational awareness is not limited to perceiving, but has multiple levels. This is described using the Endsley model (figure 2.8).

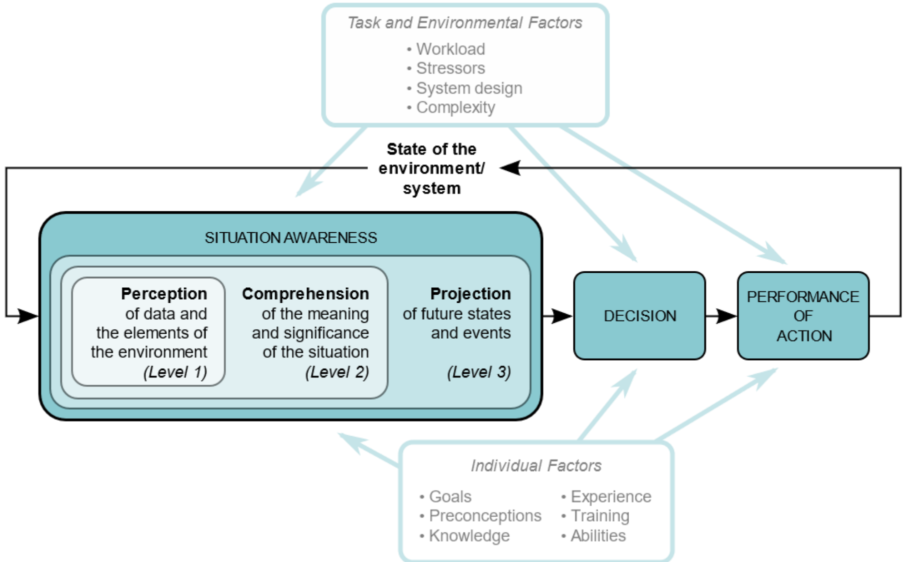


Figure 2.8: Endsley model for situational awareness

The first step is to acquire situational awareness. This is based on three different levels of information processing [Kalloniatis et al.(2017]:

Perception Data is merely perceived.

Comprehension Interpretation of data, enabling understanding of relevance in relation to tasks performed and goals to be attained. Forming a holistic picture of the operational environment. Identifying the significance of objects and events in that environment.

Projection Making a forecast for likely future states of the situation. This is based on the interpreted data, experience and knowledge.

Based on the situational awareness, an decision is being made which results in an action. Changing the system and repeating the whole process. However there are factors which influence the effectiveness of this process. These can be internally or from the environment. Where automation is less prone to environmental factors, will it have a disadvantage when it comes to setting goals, preconceptions, acquiring knowledge or learning from experience. As many of the machine learning techniques are too much of a black box approach, or are not yet effective for the assignments where ships have to navigate for example. There's also that indefinable matter of common sense that humans have but robots lack. Hundreds of thousands of years of evolution have provided us with a pretty good ability to recognize and make sense of things.

Whereas the human operator is more prone to environmental factors. Where workload is a big factor in the ability to concentrate and thus the ability to forecast future states and thus make the right decisions. The workload might be too high due to an overload of information [Speier et al.(1999], when tasks are too easy [Washburn and Putney(2001], or when limited attention is desired for a long time, and something unexpected happens [McMorris et al.(2018].

These factors do only consider the single individual within the human operator team. But with larger ships there are multiple persons at the bridge, all with their own responsibilities. Research has shown that many of these crews have multiple cultures and nationalities work next to each other. Which often have a agreed working language which is not their first. This leads not only to minor irritations. But in some cases to hazardous situations [Hetherington et al.(2006]. Certainly when conversations happen via a radio with some noise.

2.1.4 Procedures

To become a certified seafarer, different skills and knowledge must be acquired. The International Maritime Organization (IMO) has developed several conventions to standardize this knowledge globally, the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) is leading here. This ensures that ships sailing in international waters have skilled crew which know what they can expect from other vessels. This also means they have navigational abilities such as plotting on a radar. But they also have knowledge of the conventions and systems used for safe navigation. Below some of these are explained in more detail. Followed by a description of known flaws of these systems and differences when compared to procedures used in practice.

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

The COLREGs set out the navigational to be followed by ships and other vessels at sea, to prevent collisions between two or more vessels. Although rules for navigating vessels inland may differ, the international rules specify that they should be as closely in line with the international rules as possible. In most of continental Europe, the Code Européen des Voies de la Navigation Intérieure (CEVNI, or the European Code for Navigation on Inland Waters) apply. In the United States, the rules for vessels navigating inland are published alongside the international rules.

Prior to the development of a single set of international rules and practices, there existed separate practices and various conventions and informal procedures in different parts of the world, as advanced by various maritime nations. As a result, there were inconsistencies and even contradictions that gave rise to unintended collisions. Vessel navigation lights for operating in darkness as well as navigation marks also were not standardised, giving rise to dangerous confusion and ambiguity between vessels at risk of colliding. Different nations already came up with their own set of rules. But the first version was amended together with SOLAS in 1960. Additions were made including traffic separation schemes in 1972.

The COLREGs includes 41 rules divided into six sections: Part A - General; Part B - Steering and Sailing; Part C - Lights and Shapes; Part D - Sound and Light signals; Part E - Exemptions; and Part F - Verification of compliance with the provisions of the Convention. There are also four Annexes containing technical requirements concerning lights and shapes and their positioning; sound signalling appliances; additional signals for fishing vessels when operating in close proximity, and international distress signals.

Where part B is most relevant for this research, with subject like safe speed, obligation to determine risk of collision and take action with all means available, how to act in different situations with other ships, or in restricted waterways.

Standard Maritime Communication Phrases (SMCP)

As navigational and safety communications from ship to shore and vice versa, ship to ship , and on board ships must be precise, simple and unambiguous, so as to avoid confusion and error, there is a need to standardize the language used. This is of particular importance in the light of the increasing number of internationally trading vessels with crews speaking many different languages since problems of communication may cause misunderstandings leading to dangers to the vessel, the people on board and the environment.

In 1973 IMO started to develop the Standard Marine Navigational Vocabulary (SMNV), which was replaced by the SMCP in 2001. The ability to understand and use the SMCP is required for the certification of officers in charge of a navigational watch on ships of 500 gross tonnage or more. To assist in greater safety of navigation and of the conduct of the ship. To standardize the language used in communication for navigation at sea, in port-apporaches, in waterways, harbours and on board vessels with multilingual crews. Which is all instructed at maritime training institutions. These are not intended to supplant or contradict COLREGs or special local rules or recommendations made by IMO concerning ship routeing. Just as radiotelephone procedures should be followed strictly as set out in the ITU Radio Regulations.

It is a collection of phrases used to standardize and simplify the communication, where synonyms and contracted forms are avoided. Some examples of the usage of SMCP are shown below, including message markers to indicate the type of message:

Advice Stand by on channel 6 - 8.

Information The fairway entrance is: position: bearing 1-3-7 degrees true from North Point Lighthouse, distance: 2 decimal 3 miles.

Warning Buoy number: one - five unlit.

Intention I intend to reduce speed, new speed: eight knots.

Question What are your intentions?

Instruction You must alter course to starboard.

Request Immediate tug assistance.

2.2 Difference between theory and practice

How does it go in practice, experience.

Certainly in inland water or near coast conversations might be in natural language, instead of SMCP.

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

2.3 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...

- Radio communication
  - Conversational agent using Standard Maritime Communication Phrases (SMCP)
  - Availability on Very High Frequency radio (VHF)
  - Automatic Identification System (AIS) messages
- Visible signals
  - Light signals
  - Flags
  - Mast head signals
  - Heading, position and movements
- Audible signals
  - Horn
  - Speakers
- Distress, urgency and safety signals
  - Flares
  - Smoke

e.g: VDES

3 | Accidents

In the last centuries much have changed to improve the safety of vessel and decrease the risk for collision. Some were reactions to major accidents which occurred. Such as the disaster with the TITANIC in April 1912, which triggered the development of SOLAS. But also new innovations, such as the introduction of Global Positioning System (GPS), ARPA and AIS. But still accidents occur. To get insight what could result in hazardous situations. Four accidents are discussed, showing the importance of proper communication on different levels. The accidents which will be discussed are:

- Collision between MV AL ORAIQ and MV FLINTERSTAR
- Collision between MV ARTADI and MV ST-GERMAIN
- 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

3.1 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 3.1. 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 3.1: 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)]

3.2 MV ARTADI and MV ST-GERMAIN

An example where the COLREGs were followed but still resulted in two persons killed is the collision between MV ARTADI and MV St-Germain on 21 February 1979. The Liberian bulk carrier ARTADI collided with the passenger ferry ST-GERMAIN in the Dover Strait, killing two people and injuring four more. An illustration of the accident is shown in figure 3.2. Both ships followed COLREGs according to the accident report. Due to a lack of communication and wrong presumptions on the intentions, did the accident occur.

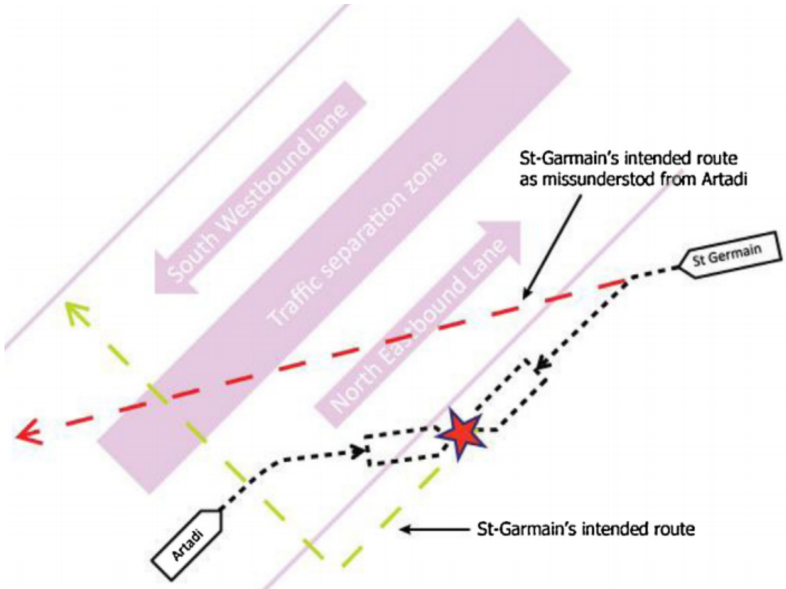


Figure 3.2: Illutstration map of approximate collision location

The ferry was spotted in good time on the radar of the ARTADI. Coming from starboard, ST-GERMAIN was the stand-on ship according to rule 15 of the COLREGs. The pilot and master of the ARTADI expected her to keep speed and course and started to make a starboard turn to give way. However, on-board the ST-GERMAIN the intention was not at all to cross the traffic separation scheme diagonally in front of ARTADI, but instead to turn port and follow outside the boarder of the NE going traffic lane until the traffic cleared and she could make the crossing at a right angle (according to rule 10c) [Porathe et al.(2013].

3.3 USS FITZGERALD and MV ACX CRYSTAL

A more recent well-known collision was between the USS FITZGERALD and ACX CRYSTAL on 17 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 3.3. 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.

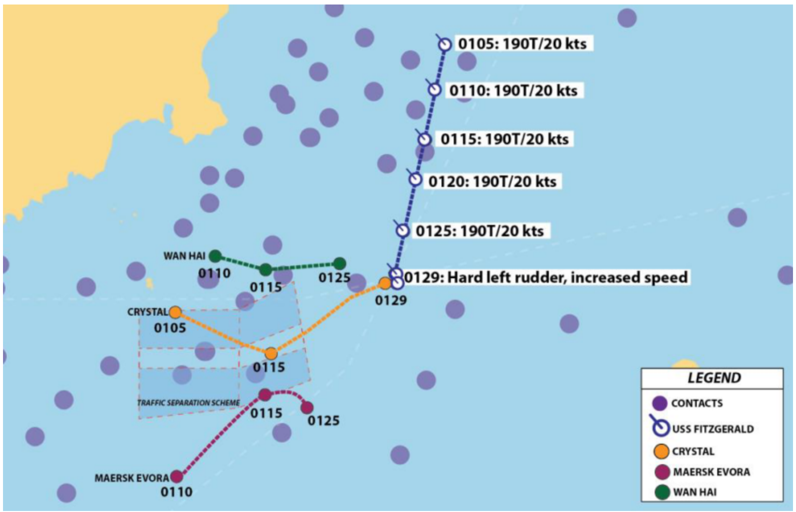


Figure 3.3: Illutstration map of approximate collision location

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)]

3.4 USS JOHN S MCCAIN and MV ALNIC MC

Even more recent is the collision between the USS JOHN S MCCAIN and ALNIC MC on 21 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 3.4. 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.

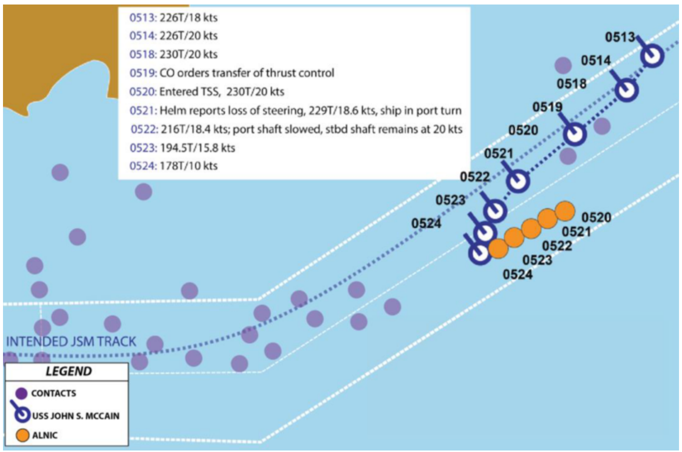


Figure 3.4: Illutstration map of approximate collision location

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)]

3.5 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 3.5 the fluctuations in heading can be seen of the CONTI PERIDOT.

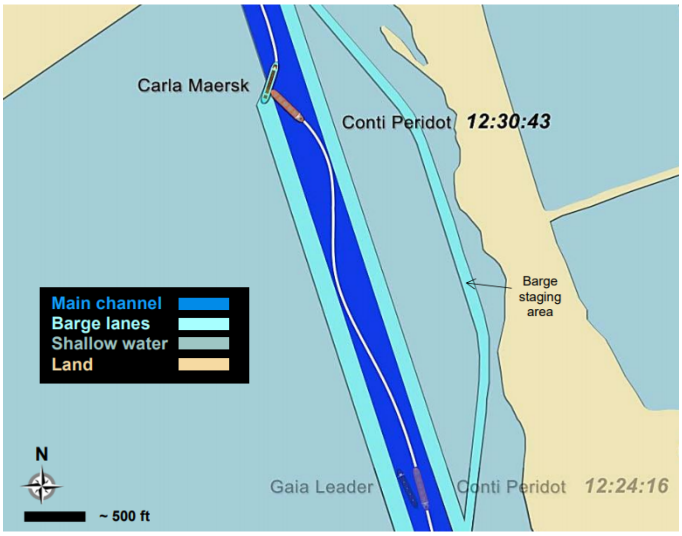


Figure 3.5: Illutstration map of approximate collision location

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)]

3.6 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

4 | Steps towards the future

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, being connected and able to message instantly is normal nowadays. Thereby also having the information where and when you want it. Many projects are working on manned and autonomous vessels. They have to build upon the previously developed technologies wich are currently used. These technologies are mentioned in chapter 2. This chapter will discuss the steps which will be taken in the near future. First, why the step towards autonomous and unmanned is taken. Followed by a description of current projects to develop new technologies. To finally identify that which challenges will most likely arise in this process.

update with info from Ikroh Yoon

4.1 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. Thereby should be considered that the projects are using different automation levels. These different levels are shown in figure 4.1.

Better figure with automation levels

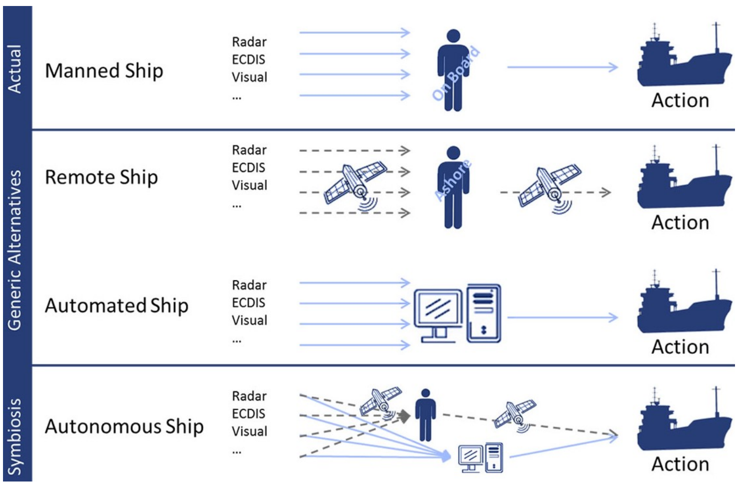


Figure 4.1: EXAMPLE-infographic: automation levels

4.2 Projects

The research project MUNIN has been one of the major projects by a consortium of shipbuilders and scientists. The name is an abbreviation for Maritime Unmanned Navigation through Intelligence in Networks and originated from WATERBORNE, an initiative from the EU and Maritime Industries Forum, supporting cooperation and exchange of knowledge between stakeholders within the deep and short sea shipping industry. They did an initial research 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.

4.2.1 Exploratory projects

Different project worked on the vision about the future of shipping, examples of these projects are:

- One Sea – Autonomous Maritime Ecosystem by DIMECC Ltd.
- Advanced Autonomous Waterborne Applications
- Unmanned Cargo Ship Development Alliance
- ReVolt

Rolls-Royce Marine is involved in different projects which are in some way follow-ups on the MUNIN project. The videos of the virtual bridge concept and the Electric Blue vessel have had many views, as this showed clearly their 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)]. They pinpointed the control room as 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. Since June 2017 is Rolls-Royce also involved in the unmanned cargo ship development alliance, which is initiated by Asian companies and classification bureaus.

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

Make infographic

Describe different levels of automation

4.2.2 Industry projects

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

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

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

Also did a Joint Industry Project (JIP) start on autonomous shipping under the name Sovereign. In this project did European companies, research institutes and the technical university of Delft partner to develop a technology to deal with difficult environments and complex transport missions within short sea and port traffic situations. Which is also applicable to other autonomous waterborne operations, such as inland waterways transport and coastal/inter-island short range ferry services. This should result in a ship for Amasus.

more info on JIP and Sovereign

Based on the above mentioned projects, can the following be seen as possible use cases:

- Local transport between factories and terminals
- Short sea shipping
- Tugs as extra actuator in dynamic positioning systems

4.3 Stakeholders

When these ships will sail, does not only dependent on the rate in which the technology can be developed. But there are also regulatory bodies, such as IMO and classification societies which need incorporate autonomous vessels in their frameworks. For them the exploratory projects are very important, as this will help to know for which ships codes should be developed. These codes include information on autonomy levels and how to certify unmanned vessels.

The next group are the shipbuilders, system integrators and suppliers for subsystems. These are responsible for the technological development. More and more shipyards try to get involved, to gain knowledge on the development process. Thereby are there companies from other industries, which see opportunities for products they already developed for planes or automotive, which could also be used on unmanned vessel. For example to connect ships, computer vision and protocol for testing systems.

The last, but probably most important are the customers, as a technology will only be used if you can make money with it. More and more companies are convinced this is possible. This are not only the chartering companies, but also their customers, such as Heineken, Yara and BHP.

4.4 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.

add model from sovereign

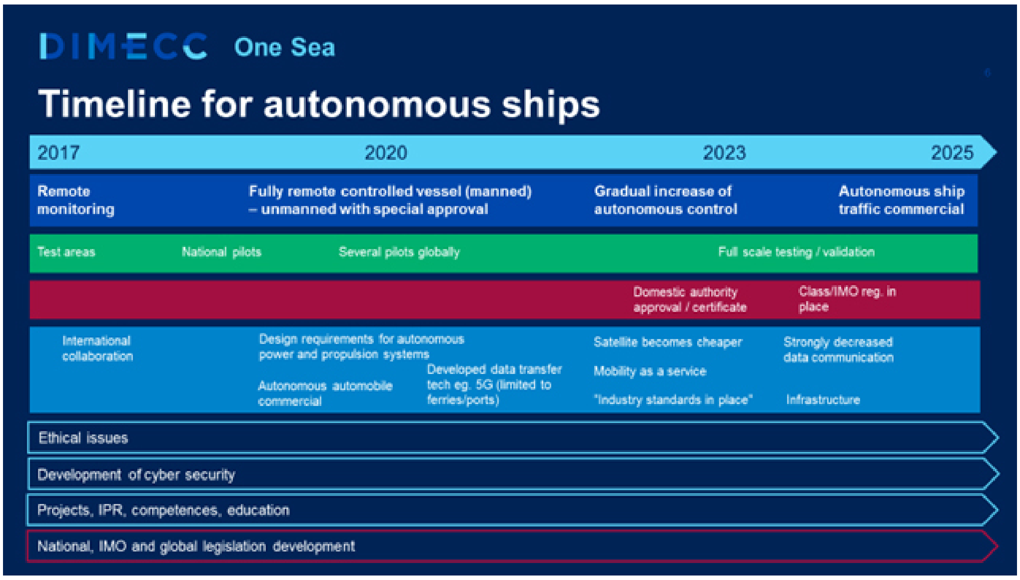


Figure 4.2: EXAMPLE-infographic: Timeline for autonomous ships by DIMECC

5 Simulation environment

In the next parts, situations will be simulated. For part II this is done to evaluate criteria for the decision model and problem identification. While part III aims to get expert feedback on the protocol.

The different scenarios will be simulated using a tool. This tool will be able to simulate the scenarios to give 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 simulated and tested. A start is made with a basic tool, which will continuously be improved. Changes in requirements might appear trough out the whole process, to deliver a better tool. The code is written in such a way that it is easy to maintain and improve by using different modules.

5.1 Foundation

The first step is to set the goals or requirements of the tool. This doesn't mean it is a full description of the tool, 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 behaviors when turning or 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, tested and visualized easily. Thereby changing ship characteristics, shared information and other inputs. Thirdly, it must be possible to show the register of possible decisions for the different vessels. To be able to validate this with seafarers. Meaning it will be a white box model.

5.1.1 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 the tool 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.

5.1.2 Requirements

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.

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: ...

Extend with more specific requirements

5.2 Architecture

describe different modules

5.3 Design specifications

5.3.1 Ship description

5.3.2 Environment description

5.3.3 Hydrodynamic model

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.

Turning rate rudder: 2,3 deg/s in regulations, 2,5 based on [Artyszuk(2016)], 3 deg/s based on [Molland and Turnock(2007]. $a_H = 2.5$ empirical amplification factor of (effective) rudder force due to hull-rudder interaction [0.6]

5.3.4 Radio

The area in which situations are tested are not larger than the radius of an VHF radio (about 20 NM - IMO regulations)

`http://solasv.mcga.gov.uk/m_notice/mgn/mgn324.pdf` - p8

5.3.5 Controller

Based on the waypoints there is a simple controller to adjust the rudder angle. This controller steers based on the relative angle between the waypoint and the current position. This is done in the *adjustRudder* function. The distance and relative angle is calculated, this is used in a simple decision tree to decide on the rudder angle, which is similar to a so-called "proportional controller". For this simulation it will give enough accuracy. For a better result, a "PID-controller" could be implemented:

Relative angle (°)	Rudder angle (°)
25-180	35
10-25	25
0-10	Relative angle $*$ 8/10

Table 5.1: Rudder angle based on relative angle

5.4 Build

printscreens
User interface
Graphs
Quality/Dependency analysis (dt vs runtime)
Currently implemented (level of intelligence) Currently is a hydro model implemented, you are able to steer the ship or use waypoints and a background image can be used to show the map.

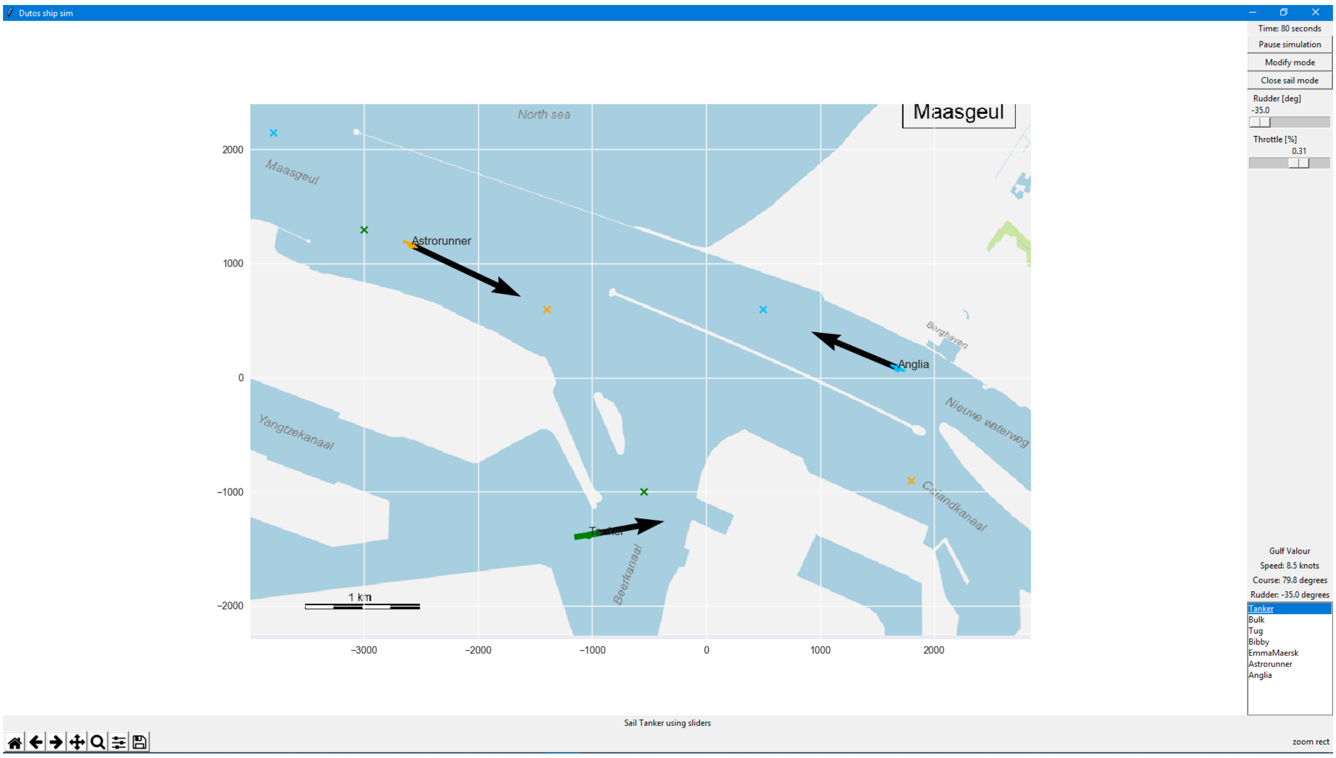


Figure 5.1: Example of evaluation tool

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 and done by an agent. However, the steps taken to get to the right decision are similar, as shown in the model from chapter 1. The insights acquired from the decision process can be used to determine manoeuvrability requirements.

The first phase of observation starts with updating the mental model and is followed by a phase where different chunks of information are connected. This means situations and scenarios can be identified. This is the start of the decision making process in which different trees are used to identify potential hazards and problems which will result in strategies. These strategies are finally narrowed down to the actions. The different nodes and trees are discussed in chapter 6.

More detailed descriptions of the different phases within the decision making process are discussed in the next chapters. First the identification of the situation and scenario is discussed in chapter 7. Every step in the trees, is taken by evaluating criteria. These criteria determine if there are hazards and which manoeuvers are feasible. This works in two ways, while sailing this can be used to determine the right strategy. While the designer can use these criteria to ensure a ship can sail safely in specific situations. The criteria to evaluate what kind of problem there is are described in chapter 8. The criteria used to evaluate if strategies are feasible are described in chapter 9. In this chapter is also described how designers can use these manoeuvers to determine if their ship can manoeuvrer safely. To evaluate if these criteria are useful, the tool as described in chapter 5 is used. Including the manoeuvring model and simulation environment. These are also used to run several scenarios and see how these criteria affect the decision making process.

The result of this part is a design matrix which can be used by designers to determine the manoeuvring requirements and moment when decisions should be made. This is done for some specific manoeuvers, showing the minimal time and distance needed to make decisions in order to have a safe distance between vessels. This depends for example on the manoeuvring characteristics, speed and type of manoeuvrer.

6 Decision making process

Using a rule-based time-domain decision model, can be determined what the situation is and what problem might occur. Using tags for the nodes in the decision tree, this can be done in a structured way, which will be discussed in this chapter. First the decision phases are described. Followed by lists of tags used to identify scenarios and situations. Combining this with the rules, will result in the decision model. Also the criteria necessary to go trough the steps are discussed. The aim of this decision model is to avoid communication.

6.1 Decision phases

The decision making process has different phases. This can be seen in the process diagram how these phases relate. This is shown in figure . These different phases are also described in table 6.1.

add process diagram

Class	Description
Situation identification	The first step is to identify the encountered situation, to determine which criteria are relevant.
Problem identification	The second step is to determine if there is a problem, as there is only a change in strategy needed when this is the case.
Strategy	If there is a problem, a new strategy should be chosen, this is based on the evaluation of the criteria.
Action	From this strategy, different actions will follow.
Result	Finally the result is evaluated, in a similar manner to the problem identification.

Table 6.1: Description of phases in decision model

6.2 Tags for decision making

What happens in the phases as described above tags are used. These tags describe in short what kind of situation, problem, strategy, action or result there is. By using the same terms, confusion is avoided. Definitions for those terms are given in this section.

Encountered situations

This is the first step to limit the about of steps needed to get to the right strategy. The identification process is described in table 6.2 and section 7.1.

Tag	Description
Passing	The paths of both ships are in opposite direction, and do not cross.
Crossing	The final direction of both ships differs, but they do cross.
Merge	The final direction of both ships is the same.
Over-taking	The paths of both ships are the same but at different speeds.

Table 6.2: Tags for different situations

Identification of problem

To identify if there is a problem, different criteria are being evaluated. These criteria are described in chapter 8. In table 6.3 the nodes and branch tags within the decision tree are discussed to evaluate if there is a problem, and what kind of problem there is.

Tag	Evaluation
Closest point of approach	Good; Too close
Crossing point	In front; Behind
Crossing distance	Good; Too close
Relative speed	Faster; Same speed; slower

Table 6.3: Criteria and result of evaluation to determine problem

Possible strategies

Tag	Description
Follow planned path	
Move away from other path	
Stay parallel for longer	
Adjust speed	
Abort over-taking	
Move away from other position	Check if this is to starboard, otherwise communicate
Communicate	

Table 6.4: Tags for different strategies

Possible actions

To execute a strategy, different actions are taken. These action are a combination of an action type, and a moment to execute action. In table 6.5 and 6.6 these are described. The criteria to determine if an action is possible are described in 6.7.

Tag	Description
Continue without change	
Evasive manoeuvrer to starboard	
Evasive manoeuvrer to portside	
Slow down	
Speed-up	
Emergency stop	
Communicate	

Table 6.5: Types of actions

Tag	Description
Now	
In ... minutes	
After action ...	

Table 6.6: Time-domain for action

Tag	Evaluation
Closest point of approach	
Time till problem	
Distance till problem	

Table 6.7: Criteria to determine if action is possible

Result

Tag	Description
CPA	
Perceived risk	

Table 6.8: Tags for safe situation criteria

Tag	Description
Safe situation	
Communicate	

Table 6.9: Tags for results

6.3 Decision trees

When combing the nodes as described in the previous section, very large decision trees are obtained. As there are in every phase, a limited amount of possibilities. Is it for presentation purpose better to split the full decision tree into smaller trees. The first set of trees aims to identify the problem for different situations, this can be found in figure 6.1-6.4.

More sub-trees on choosing strategy

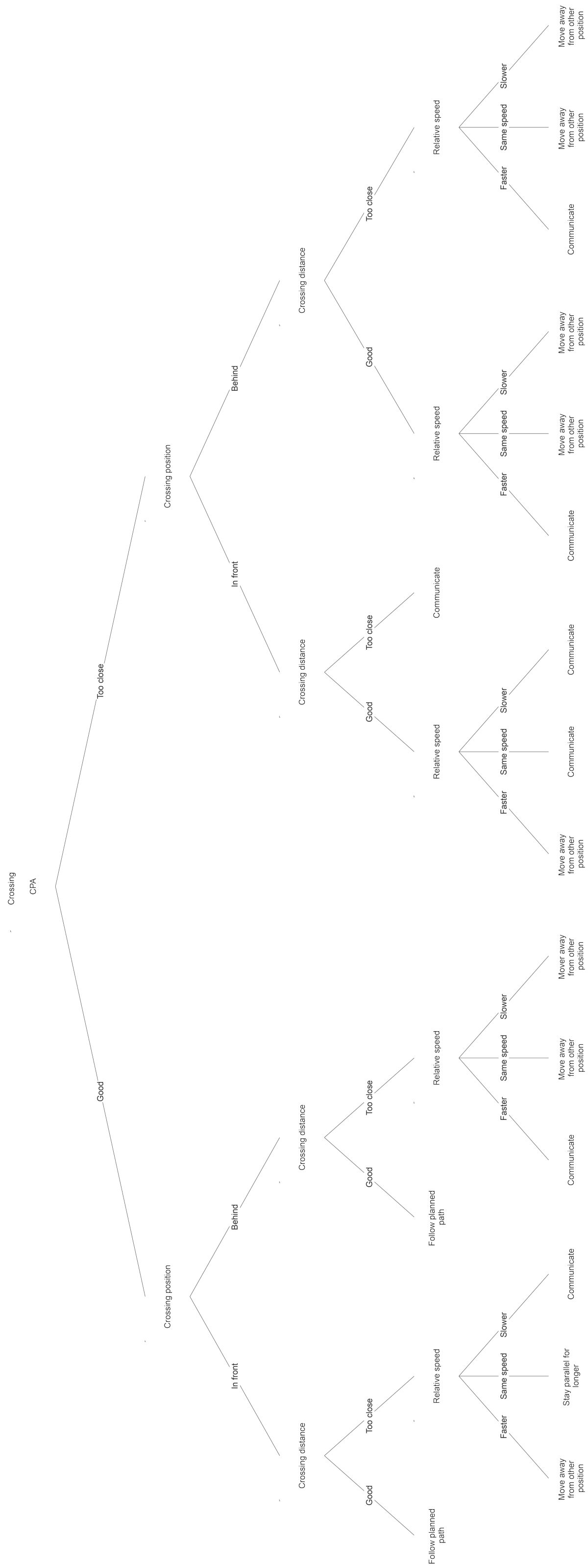


Figure 6.1: Decision tree when crossing

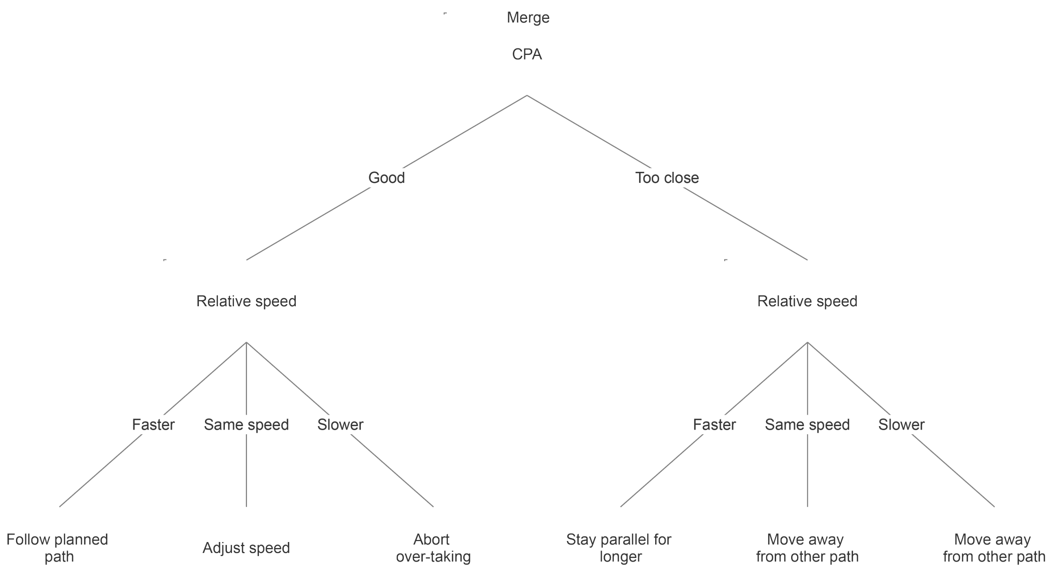


Figure 6.2: Decision tree when merging

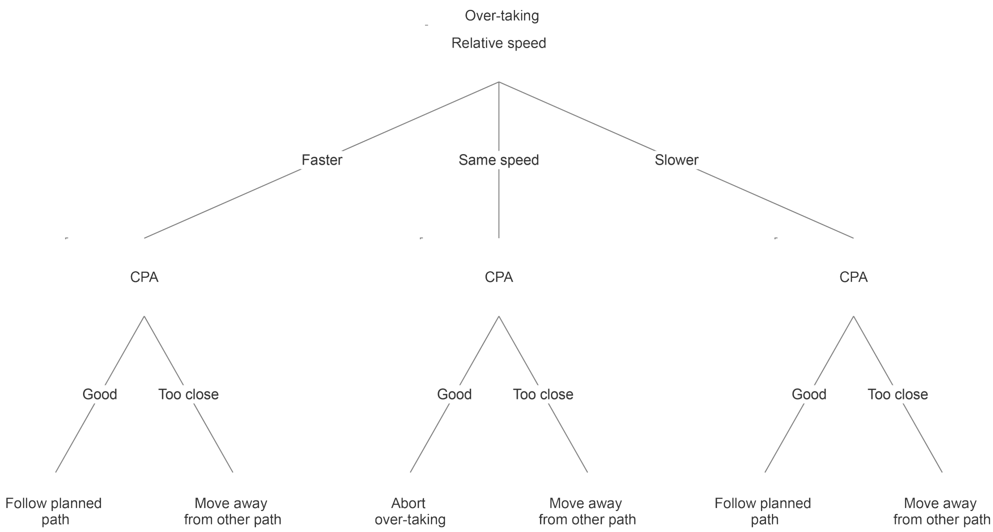


Figure 6.3: Decision tree when over-taking

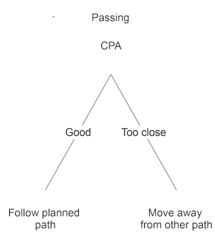


Figure 6.4: Decision tree when passing

7 | Identification of situation and scenarios

The first relevant step for this research is the step to identify the situation and scenario. This identification is used to narrow down possible strategies in the next phases of the decision making process. In this chapter, the first steps of classifying the situation are discussed. Followed by the steps taken in the orientation phase to form strategies.

7.1 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 to an over-taking situation.

Over-taking 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 will be based on figure 7.1 and 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 7.1. The boundaries are based on COLREGs and shown in figure 7.1. .

use colreg boundaries in junction and terminology (head-on, overtaking, etc.)

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 7.1: Standardized paths for situations

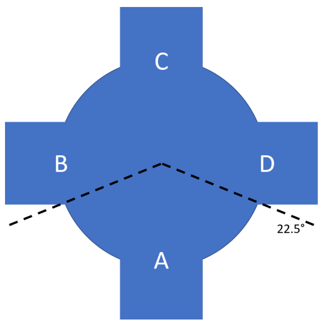


Figure 7.1: Path description

7.2 Situations which limit possible strategies

Beside this first identification of the situation. More details will be taken into account to form the right strategies. Below different factors and their consequences on the strategy are discussed.

7.2.1 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. Examples of static hazards which could be evaluated in future iterations are bridges, buoys, forbidden zones and port mouth. As possibilities for over-taking are limited in those cases for example. This means the strategies are limited.

Another limiting factor related to waterways are the difference in regulations between waterways. Most obvious are signs which forbid to over-take or meet. But others are for example to not create wash or no turning. Or more directive signs on obligated directions or speed limits. This is mostly relevant for coastal and inland waterways.

7.2.2 Actors

The second major step is the identification of dynamic objects. Those are all relevant moving objects. Most obvious 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.

Examples of such dynamic objects which limit the possible strategies are for example fishery vessels. As they might have long nets behind them while in operation. Ferries in inland waters which have priority over other shipping traffic. Other ships with limited manoeuvrability or forbidden zones around them.

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

also describe the rules, which might be based on signs

add more examples to describe consequence on strategy - Relative

7.3 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 to 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.

7.3.1 COLREGs

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

Most important rule of COLREGs, is that you are allowed to deviate from any rule if it will increase the safe operation. This is only the case when others also expect you to deviate.

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

add more examples to describe consequence on strategy

8 | Definition of criteria

To determine which problem might occur due to dynamic and static hazards, 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. First the criteria which are true or false are discussed, followed by the current and proposed algorithms to calculate the other criteria.

8.1 Calculations based on current systems

Within ARPA and ECDIS, different calculations are already being made, which can be used to evaluate if there is a problem in the current scenario. These calculations often use linearized algorithms, which results are not correct when turning. Below these calculations are discussed for the Closest point of approach (CPA) and crossing position.

add code snippets to appendix

8.1.1 Closest point of approach (CPA)

The CPA refers to the positions at which two dynamically moving objects reach their closest possible distance. This is an important calculation for collision avoidance. The linearized form uses two points moving at fixed speed and fixed direction. An example is shown in figure 8.2. Where P and Q are the moving points, with corresponding direction vectors u and v, which include the speed and direction.

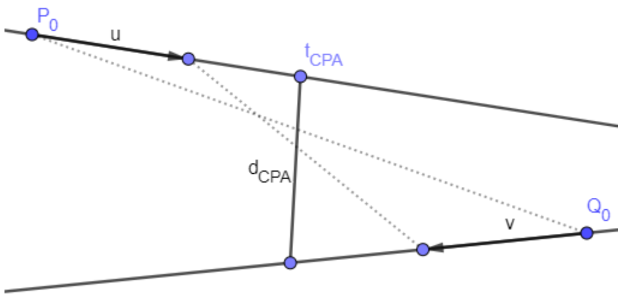


Figure 8.1: Example for Closest point of approach (CPA)

A formula can be derived for the closest point of approach. With the motion equations for P and Q, the distance can be calculated. Where P_0 and Q_0 are the current positions:

$$P(t) = P_0 + t \cdot u; \quad Q(t) = Q_0 + t \cdot v \tag{8.1}$$

$$d(t) = |P(t) - Q(t)| = |P_0 - Q_0 + t(u - v)| \tag{8.2}$$

Since d(t) is a minimum when $D(t) = d(t)^2$ is a minimum:

$$D(t) = d(t)^2 = (u - v) \bullet (u - v)t^2 + 2(P_0 - Q_0) \bullet (u - v)t + (P_0 - Q_0) \bullet (P_0 - Q_0) \tag{8.3}$$

$$\frac{dD(t)}{dt} = 0 = 2t[(u-v) \bullet (u-v)] + 2(P_0 - Q_0) \bullet (u-v) \tag{8.4}$$

This can be solved for t to calculate the moment where CPA is the smallest:

$$t_{CPA} = \frac{-(P_0 - Q_0) \bullet (u-v)}{|u-v|^2} \tag{8.5}$$

$$d_{CPA}(t_{CPA}) = |P_0 - Q_0 + \frac{-(P_0 - Q_0) \bullet (u-v)}{|u-v|^2} \bullet (u-v)| \tag{8.6}$$

If t_{CPA} is smaller than 0, the CPA is in the past, else it is in the future.

8.1.2 Crossing distance

The crossing distance is the distance between two ships if they pass each others path. This can be both in front or behind a vessel. This distance is mostly relevant for how safe a crossing situation feels. The crew on manned ships do not want to have ships too close in front of them, as they can't do an evasive manoeuvrer in those situations. The same motion equation as for CPA can be used (equation 8.1).

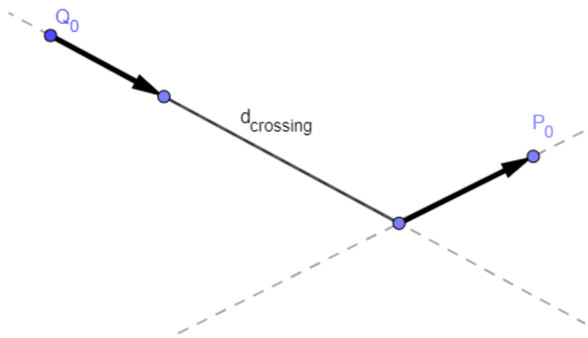


Figure 8.2: Example for crossing point and distance

In this case the distance is calculated between two points at a certain moment in time. The first step is to calculate the crossing point (cp) of the two lines:

$$P(t_{cp,p}) = Q(t_{cp,q}) \rightarrow P_0 + t_{cp,p} \cdot u = Q_0 + t_{cp,q} \cdot v \tag{8.7}$$

$$t_{cp,P} = \frac{(Q_0 - P_0) \times v}{u \times v} \tag{8.8}$$

$$t_{cp,Q} = \frac{(P_0 - Q_0) \times u}{v \times u} \tag{8.9}$$

$$cp = P_0 + \frac{(Q_0 - P_0) \times v}{u \times v} \cdot u = Q_0 + \frac{(P_0 - Q_0) \times u}{v \times u} \cdot v \tag{8.10}$$

The next step is to determine where each vessel is, when the other vessel is at the crossing point. To determine finally what the crossing distance is:

$$P(t_{cp,Q}) = P_0 + \left[\frac{(Q_0 - P_0) \times v}{u \times v}\right] \cdot u \tag{8.11}$$

$$Q(t_{cp,P}) = Q_0 + \left[\frac{(P_0 - Q_0) \times u}{v \times u}\right] \cdot v \tag{8.12}$$

$$d(t) = |P(t) - Q(t)| \tag{8.13}$$

The crossing distance (cd) for when P crosses Q and vice versa, can be calculated using the following formulas:

$$d_{cd,PQ}(t_{cp,P}) = |P(t_{cp,P}) - Q(t_{cp,P})| \tag{8.14}$$

$$d_{cd,QP}(t_{cp,Q}) = |P(t_{cp,Q}) - Q(t_{cp,Q})| \tag{8.15}$$

8.2 Proposed algorithm based on planned path

To improve the evaluation of criteria, better non-linearized methods are necessary for the calculation of the CPA and crossing point. By predicting the likely path of a vessel, better estimations can be made. 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.

Although it will result in better evaluations. Is the disadvantage that much heavier computations are needed, while also introducing uncertainty with the numerical solver. Therefore a combination can be made based on the expected route to use the linearized or non-linearized methods. The calculations have to be done for every combination of your ship and another ship which is close.

8.2.1 Bézier curve

The first iteration of the algorithm is semi-linearized. Where the path of own ship is represented by a Bézier curve, based on its waypoints and strategy. To describe the Bézier curve, points have to be fitted along the planned path. This is similar to the method as described by Taams [Taams(2018)]. While the other ship is still linearized, as not enough information on the strategy and waypoints is known without introducing new systems and protocols.

For the calculation does the distance function not change. This is still $d(t) = |P(t) - Q(t)|$. However is P taken as own ship and gets a new formula using the Bézier curve. This curve has a degree of n, which depends on the way-points and can be described using the following equations:

$$P(t) = \sum_{i=0}^{n} b_{i,n}(t) \cdot P_i \quad and \tag{8.16}$$

$$b_{i,n}(t) = \binom{n}{i} t^i (1-t)^{n-i}, i = 0, \ldots, n \tag{8.17}$$

8.2.2 Closest point of approach (CPA)

The numerical algorithm used to calculate the CPA is shown below. Herein is the Bézier curve thus used for making a representation of own vessel, while other vessels are represented with the linearized function as described earlier.

1. Check if something has changed since last calculation:
   (a) No, break
   (b) Yes, continue
2. Use waypoints to determine expected path for own ship (Bézier curve).
3. Use path to determine location for each time-step.
4. Use course and speed other ships to determine their location for each time-step
5. Calculate distance between ships for each time-step:
   (a) If smaller than stored CPA, update stored CPA with calculated CPA
   (b) If larger than stored CPA, do not update
6. Return CPA

8.2.3 Crossing distance

The algorithm to calculate the crossing distance will require much less computational power, as not all time-steps have to be calculated. Just the ones where the path cross. The following algorithm can be used. It should be noted that some calculations from the CPA calculation can be reused.

1. Check if something has changed since last calculation:
   (a) No, break
   (b) Yes, continue
2. Use waypoints to determine expected path for own ship (Bézier curve).
3. Determine crossing point(s) between linear path and Bézier curve.
4. Check if crossing points exist:
   (a) No, break
   (b) Yes, determine location for crossing point(s)
5. Calculate time when ships are at crossing point(s).
6. Calculate distance between ships at time of crossing.
7. Return crossing distances.

9 Dependence of manoeuvrability on decision criteria

The criteria as described in the previous chapter are aimed to determine if there is a problem. In the case there is a problem. Different actions can be undertaken to mitigate the risk. To determine which actions are feasible different criteria are used. As these manoeuvers are complex is it usefull to develop a database with thresholds upfront. To determine these thresholds, simulation are performed for different ships and scenario's. In this chapter is described how these thresholds are calculated, using the tool as described in chapter 5.

9.1 Manoeuvrer descriptions

The COLREGs prescribe to have single bold movements, thus alterations of course or speed, should be clearly observable. To acquire this, do strategies often result in actions which can be categorized in different types of manoeuvers. Most common in extreme situations are the evasive manoeuvrer and emergency stop. The time needed to do these manoeuvers depends on the manoeuvring characteristics. These characteristics are measured using different types of manoeuvers. Most relevant in this case are the zig-zag test and turning circle. In this section these different manoeuvers are described.

add figure of these manoeuvers

9.1.1 Evasive manoeuvrer

The evasive manoeuvrer aims to increase the closest point of approach distance. Based on COLREGs is there a stand-on and give-away vessel. The stand-on vessel is supposed to keep course and speed the same, while the give-away vessel is supposed to manoeuvrer. There are many way an evasive manoeuvrer can be done. But to simplify the calculation, is for now chosen to use a perpendicular crossing situation, where the give-away vessel aims to end the manoeuvrer with the same course as before. In figure 9.1 the paths are plotted for a Tug and Tanker. The manoeuvrer is simulated for different speeds and with different maximum course changes. Figure 9.2 shows how the rudder is changed during the evasive manoeuvrer. Also can be seen that the speed drops, due to a drift angle.

9.1.2 Sea-trial

During the commissioning of a ship, a sea-trial is performed. This has many purposes, but one of them is to determine if the manoeuvrability is as expected, so that the ship can be classified. Different manoeuvers are used to determine this. In this section these will be described.

Emergency stop

Not yet implemented

Zig-zag test

The second test is the zig-zag test. Herein is the overshoot tested when changing course. This is done by putting the rudder at an angle of 10 or 20 degrees to port side, till the course change is also 10 or 20 degrees, than the rudder is changed to starboard side. This is repeated several times. The overshoot is determined by measuring the course changes. In figure 9.3 the paths are shown for several ships. While in figure 9.4 the rudder, course and heading changes are shown.

Turning circle manoeuvrer

The final test is to determine the turning circle of the vessel. The rudder is put at a 20 or 35 degrees. That the ship will start turning. After a while the ship will turn at a constant speed and course change. The results of this test are an advance distance, which is the distance from starting to give rudder, till the ship has turned 90 degrees. The tactical diameter, which is the distance between the starting point and maximum distance to the side. And finally the steady turning diameter, which is the diameter of the turning circle when speed and course change are constant. The paths of different ships at design speed are shown in figure 9.5.

9.2 Relevant variables

- Turning circle
- Advance distance
- Tactical diameter
- Passing distance
- Time needed for manoeuvrer
- Distance before problem occurs
- Starting speed

9.3 Dependency analysis

- Time used to limit overshoot (changetime)
- Speed of other vessel

9.4 Trial results

Results of trials showing the dependency of passing distance on distance till CPA and current speed are shown in figure 9.6 on page 58.

As can be seen does there exist an asymptote at a distance for every ship and speed. This distance is equal to the distance needed to turn 90 degrees. As in this case the ship can sail parallel to the course of the other vessel. Therefor no simulation are done for these distances. Only the minimal distance for a certain passing distance is needed.

Also other the course change, time to execute and advance distance are plotted. But less conclusions can be drawn from this. Examples are shown in figure 9.7 on page 59. From this plots can be concluded that the distance before the accident and current speed influences the maximum passing distance. Where should be considered that the line also shows where the previously mentioned asymptote is.

9.5 Examples of resulting design matrix

Proefvaarten met schepen om draaicirkel en zigzag te bepalen.
Van schepen is bekend hoeveel tijd en afstand kan worden gewonnen met welke manouvre.
Dit combineren kan worden gebruikt tijdens scheepsontwerp.

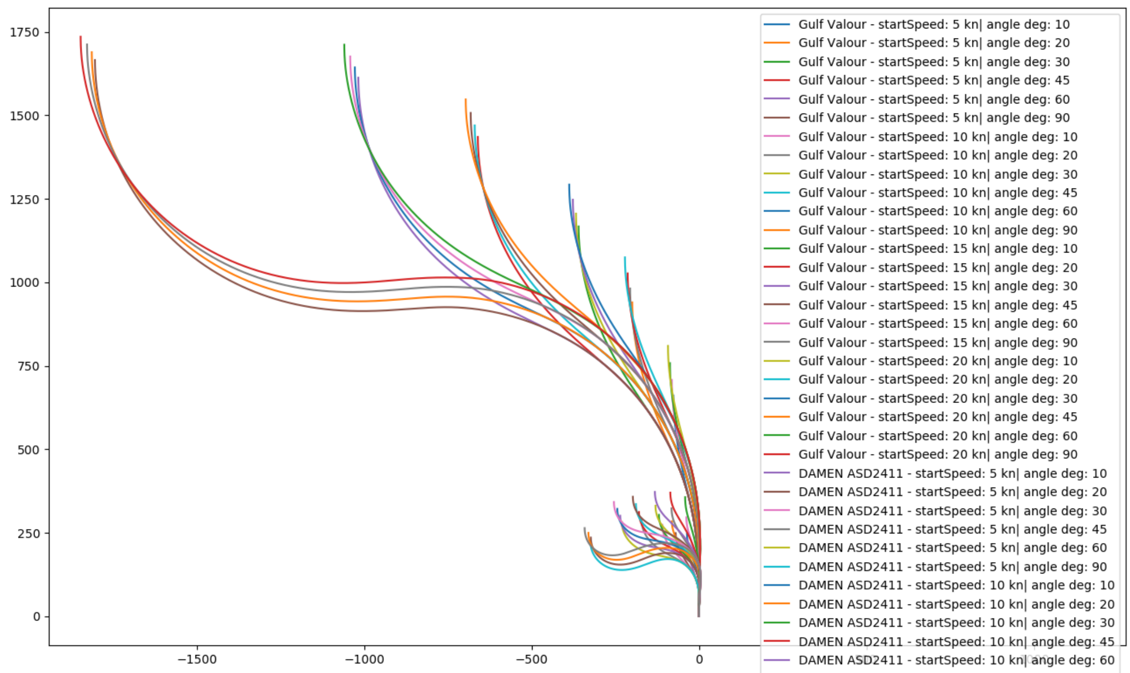


Figure 9.1: Evasive manoeuvrer at different speeds and angles, with ASD Tug and Tanker

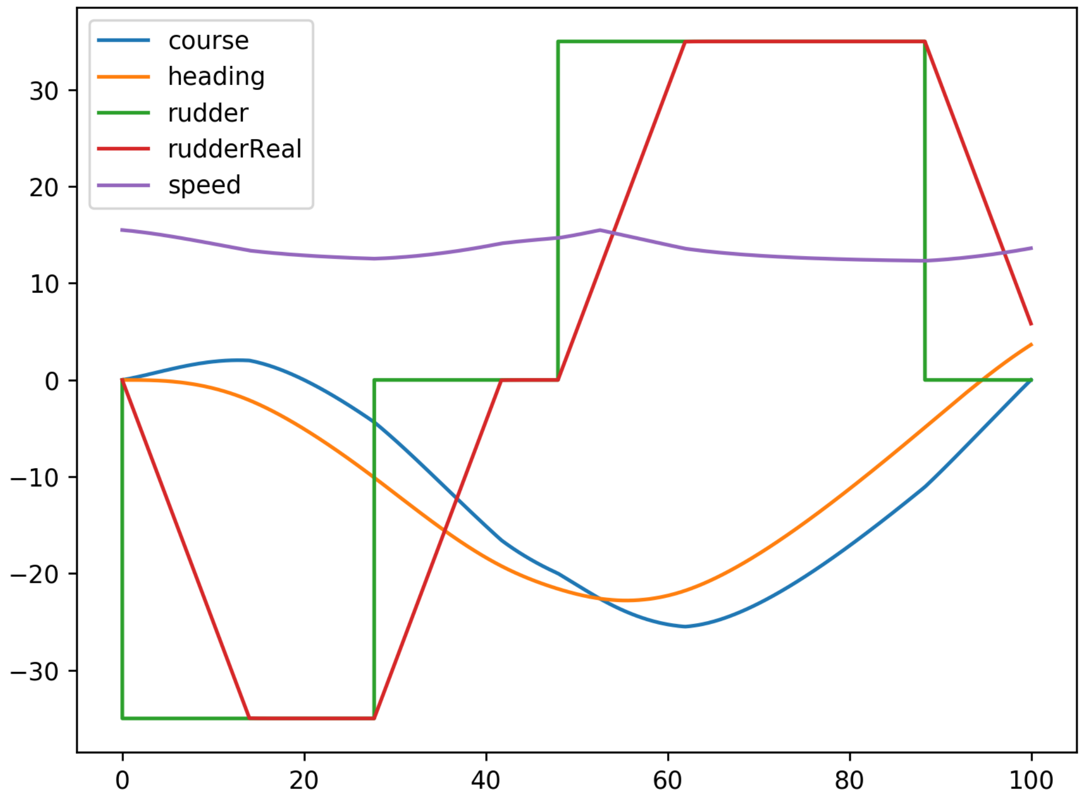


Figure 9.2: Evasive manoeuvrer till 20 degrees with Astrorunner

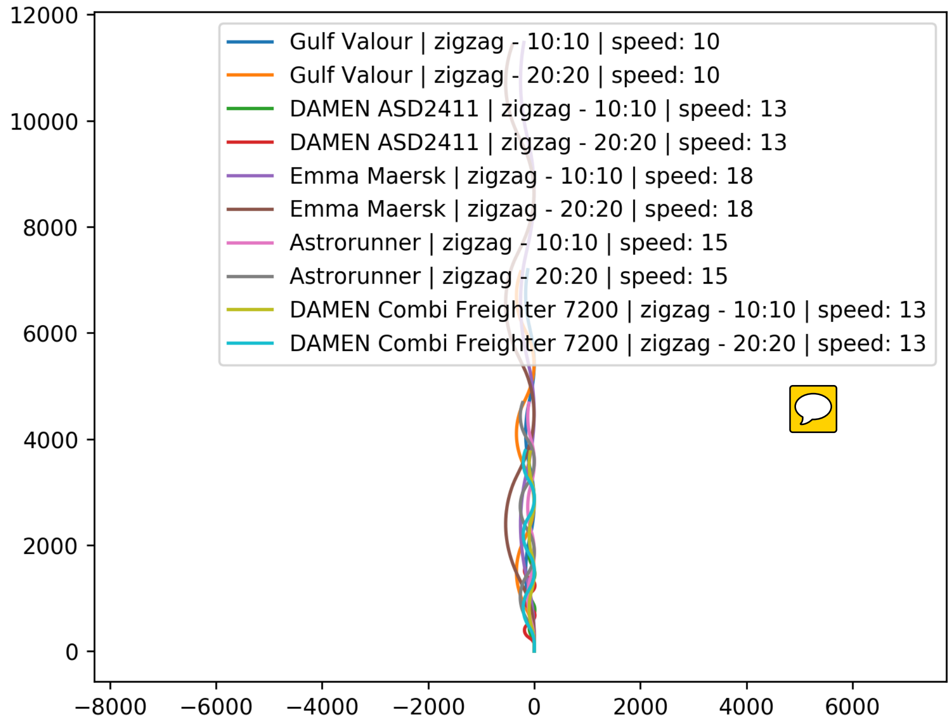


Figure 9.3: Paths from both zig-zag tests at design speed for different ships

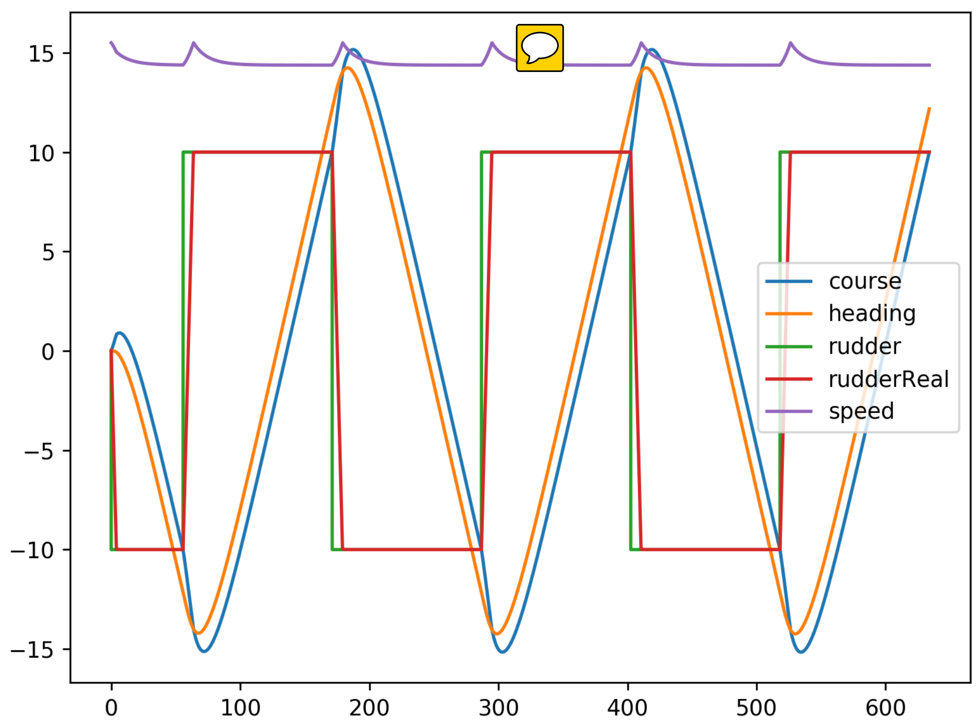


Figure 9.4: Zig-zag 10:10 test with Astrorunner (140m cargoship)

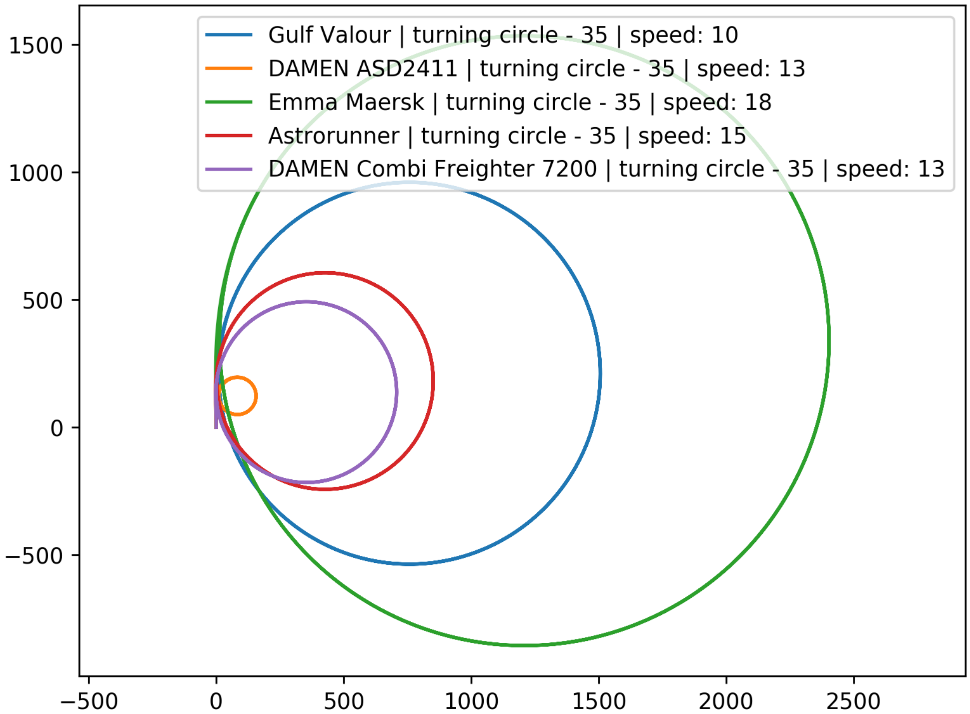
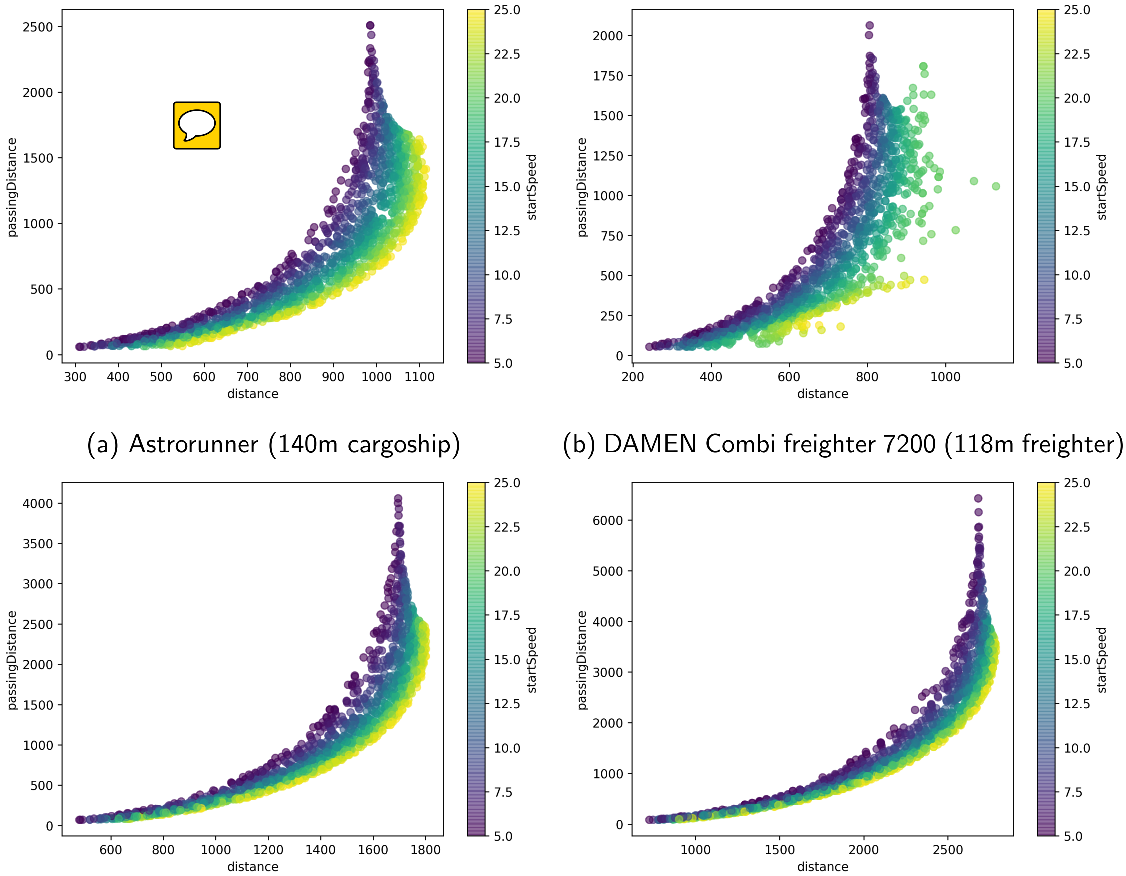


Figure 9.5: Paths from turning circle tests at design speed for different ships



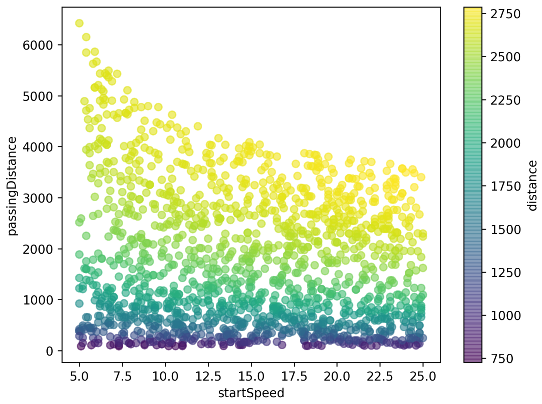
(a) Astrorunner (140m cargoship)

(b) DAMEN Combi freighter 7200 (118m freighter)

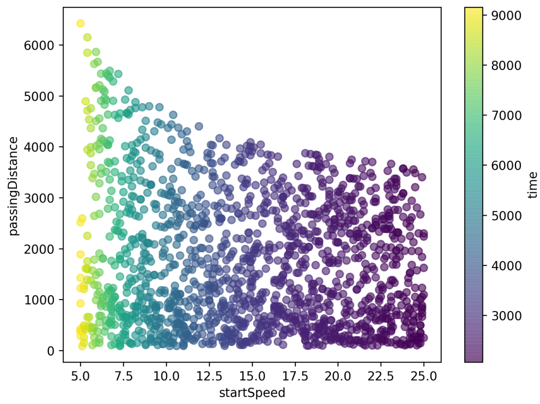
(c) Gulf Valour (250m tanker)

(d) Emma Maersk (400m containership)

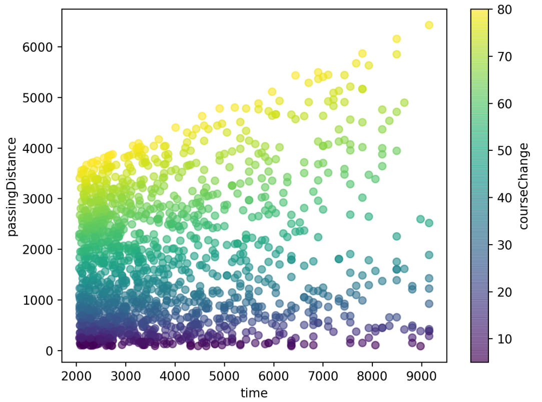
Figure 9.6: Dependency of passing distance on distance till CPA and current speed



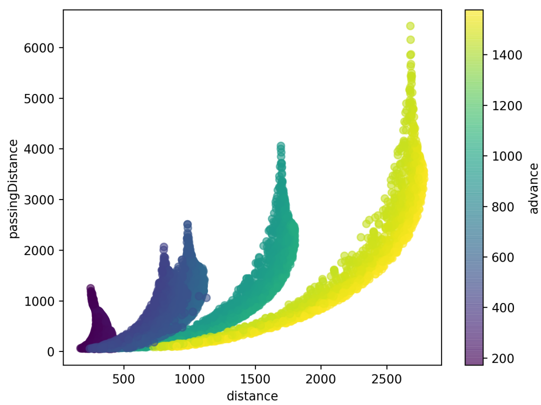
(a) Emma Maersk - Start speed, passing distance and distance till accident



(b) Emma Maersk - Start speed, passing distance and time



(c) Emma Maersk - Time needed, passing distance and course change



(d) Advance based on distance and passing distance

Figure 9.7: Other plots

10 | 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.

10.1 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.

10.1.1 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 10.1. 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*

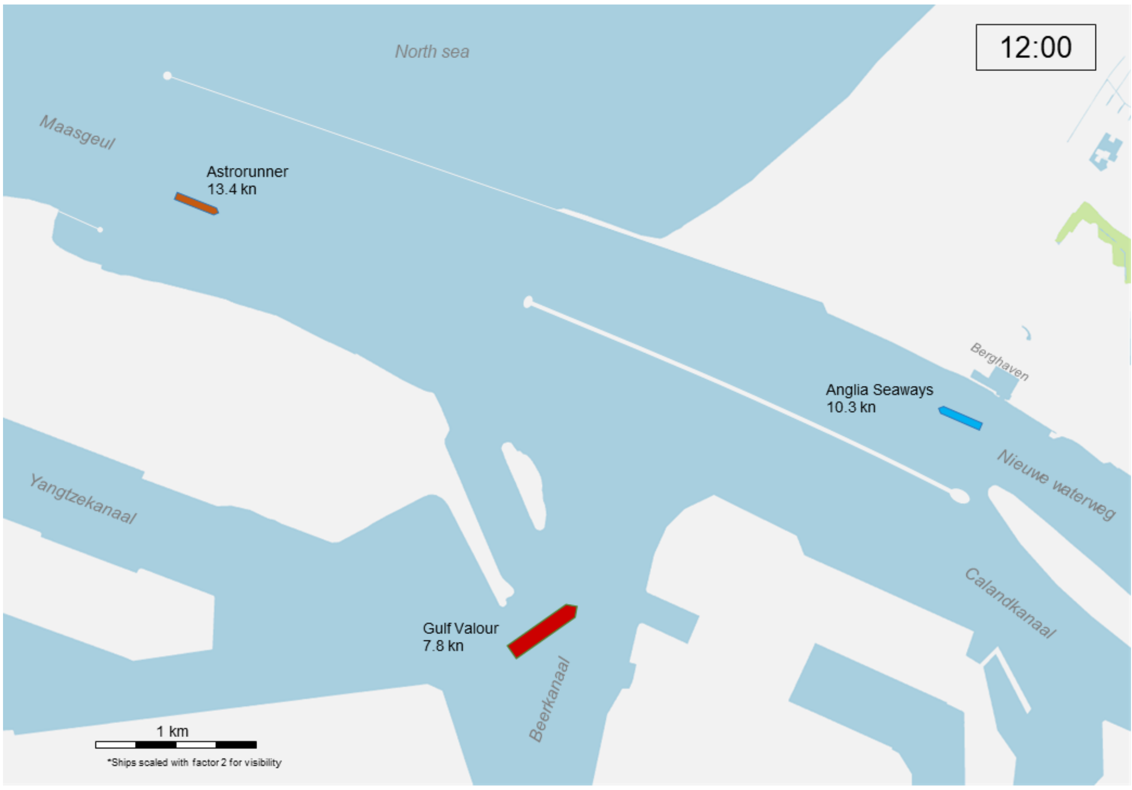


Figure 10.1: Situation sketch 12:00, with area which can be observed by Gulf Valour

10.1.2 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.

10.1.3 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 2.3, 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 screen-shot of simula-tion

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

10.1.4 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

10.2 Second scenario

discuss another scenario

10.3 Relevant lessons

summarize relevant lessons, and what NOT should be forgotton

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

Protocol to enable teamwork between manned and unmanned ships

In the previous part a decision model is described which tries to avoid communication between vessels by taking the right decision at the right moment to ensure an unimpeded voyage. However this is not always possible. 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 via VHF is used to acquire the missing information or discuss strategies with other ships. Thus to have unmanned vessel sail between manned vessel, a protocol is needed.

add link to abstract model

A protocol defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message. Where it is most straight forward to use verbal communication, will it not be limited to this, as it might result in better situational awareness for both the manned and unmanned to use other means, such as visible signals.

The communication which currently happens between vessels is mostly when COLREGs are not followed, or when intentions are not clear. Other communication which will not be within the scope of this research, such as the communication with traffic controllers and how conversations are interpreted by other vessels. Thus this research is a starting point to develop a full protocol needed for the acceptance of unmanned vessels.

Using the situated Cognitive Engineering (sCE) method, this protocol 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].

The first step is to create a foundation. The current situation of the problem is discussed, which have to be solved. Thereby considering existing knowledge which might be relevant to solve the problem and finally in short the envisioned technology. The next step is to define the system design specification. In which scenarios are described which show how the problem is solved. From this can be extracted what should be designed and why this is done. Using this a design is made which is being evaluated to make improvement in next iterative steps.

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 unambiguious. 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 right 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 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.

The reason safety related verbal communication is needed, when you will deviate from the rules, deviant behavior is registered, or more information is needed to take the right decision. Cases where this occurs is when there is no visual. For example due to bad weather, obstacles like bridges and terminals, or the information received via AIS is not reliable.

Marker words are used to introduce the content and purpose of the communication. Below for each of the marker words an example is given.

Advice Stand by on channel 6 - 8.

Information The fairway entrance is: position: bearing 1-3-7 degrees true from North Point Lighthouse, distance: 2 decimal 3 miles.

Warning Buoy number: one - five unlit.

Intention I intend to reduce speed, new speed: eight knots.

Question What are your intentions?

Instruction You must alter course to starboard.

Request Immediate tug assistance.

After this message there is a confirmation that the message is received, followed by a repetition of the send message, or an answer to the question. Indicated with the corresponding marker word.

The 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 different actors and discussing their related problems.

Primary actors

The focus of this research will be on bridge-to-bridge communication. This means the most important actors can be divided for the unmanned and manned vessel:

- Manned vessel
  - *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. A risk for them is information overload or underload [Neerincx(2008)].
- Unmanned vessel
  - *Controller agent*. This agent is responsible for situational awareness. Thus getting safely from A to B. It will decide on the navigational strategy, it will do this based on the information it can acquire via all different means. Including newly developed

communication protocols. His duties are similar to the duties of the officer of watch as described for the manned vessel.

- Other vessels
  - *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.

Secondary actors

Beside the first group of actors, others could also be influenced by the new protocol. Although they are not within the scope of this first design cycle, they should be considered to avoid problems such as information overload on current communication channels or confusion.

- Only recipients
  - Crew on vessels which are not traveling.
  - Shipowners of unmanned vessels, monitoring vessel from other location.
- Not within scope of the research
  - Vessel traffic controllers
  - Crew which are in distress and require assistance

Goals

The main goal is to ensure reliable sharing of information, without the risk for information overload or misunderstanding. Such that manned ships will trust unmanned ships to choose the right strategy. As manned ships can be informed, using natural language describing the reasoning of unmanned vessels.

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.

Using the same philosophy, it might be possible to develop also a protocol for communication with traffic controllers in later iterations. This is certainly relevant it is also not feasible for them, to have new systems to communicate and instruct unmanned ships.

Infeasible solutions

The easiest solution for unmanned ships would be to just install a new system. This is however not feasible as mentioned before. To implement this it 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. The key problems relevant for human factors are the information overload, situational awareness, autonomy, and learning a new protocol. Thus the following questions should be answered:

- When does information overload occur?
  - In case of divided attention there is a high risk for information overload and distraction by low priority messages. Therefor the developed system should be context aware so it can limit this risk by adapting the message to the situation [Arimura et al.(2001].
  - Overload might appear due to a competition for the operator's attention that is going on between different information items. If many tasks are handled by automated systems, the operator can deal with high workload circumstances, but will suffer from severe underload during quiet periods, probably losing his or her situational awareness [Neerincx(2008)].
  - The information acquired at one particular moment does not necessarily serve for high-level situation awareness, for the user needs to recall the previous related information to understand the situation thoroughly. But constantly providing information might not be the solution because there will be a huge risk of information overloading. Admittedly it is plausible to deliver needed information for the coming task by task detection, the user might still fail to keep pace to the rapid changing system and fulfill multi-threaded tasks[Porathe et al.(2014].
- Which information is needed for situational awareness?
  - Situational awareness can be enhanced by feedback, perceived information from the environment, information from other agents, as well as remote sensors. [Carver and Turoff(2007]
  - Understanding the current picture is not enough for full situational awareness. Expert decision makers must be able to project their understanding into the future. This enables them to make the decision they must take now to create the best options in the future. Projection requires to have good mental models of the

dynamic relationships between the relevant parts of the environment over time. Expers focus a lot on creating their own futures via present decisions. In turn, these decisions are formed out of their comprehension of the likely interactions of all the elements they deem both relevant and important [Gregory and Shanahan(2010].

  – A large part of sensors, automation, and operators, are used to build a common operational picture. Providing different agents with the information required to make sense of the situation [Neerincx(2008)].

- How is information perceived when acquiring it passively of actively?
  – Attention profoundly modulate the activity of sensory systems and this can take place at many levels of processing. Imaging studies, in particular, have revealed the greater activation of auditory areas and areas outside of sensory processing areas when attending to a stimulus [Palmer et al.(2007].
  – Good teamwork involves anticipating the needs of teammates and that means pushing information before it is requested. Therefore, if things are going well, there should be little need for pulling information. In this studys task, participants were instructed to push information to others, and over time master the specific timing of information sharing to the intended recipient. Findings indicate that pushing information was positively associated with TSA and team performance, and human-autonomy teams had lower levels of both pushing and pulling information than all-human teams [Demir et al.(2017].
- What is needed for successful teamwork between human and a computer?
  – People need to understand what is happening and why when a teammate tends to respond in a certain way; they need to be able to control the actions of an agent even when it does not always wait for the human's input before it makes a move; and they need to be able to reliably predict what will happen, even though the agent may alter its responses over time [Bradshaw et al.(2003].
  – Effective team communication, a fundamental part of team coordination, is crucial for both effective team situation awareness and team performance [Demir et al.(2017].
- Do people trust automated systems?
  – When using automation, the role of the human changes from operator to supervisor. For effective operation, the human must appropriately calibrate trust in the automated system. Improper trust leads to misuse and disuse of the system. [Walliser(2011)].

Is dit voldoende?

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 protocol act as expected?

- Will it solve the problem of missing information?
- Do people perceive it as easy to use and useful?
- What is the impact on attitude towards unmanned ships?

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.

- Radio communication
  - Usage of message markers
  - Conversational agent
- Visible signals
  - Light signals
  - Mast head signals
  - Flags
- Audible signals
  - Horn
  - Speakers
- Distress, urgency and safety signals
  - Flares
  - Smoke

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). Different systems which are currently used, are described in chapter 2. Below different systems and protocols are mentioned which can be used to design the new protocol. Using these already existing systems will shorten de development, learning and implementation time.

- Radio communication
  - Conversational agent
  - Negotiating agent

  - Usage of message markers
  - Availability on VHF
  - Natural language variations on SMCP
  - NATO phonetic alphabet and numbing
  - Addressed AIS message to exchange information or interrogate
- Visible signals
  - Light signals
  - Mast head signals
  - Flags
  - Heading, position and movements
- Audible signals
  - Horn
  - Speakers

Thereby is it easier to learn when its based on known protocols, such as Standard Maritime Communication Phrases (SMCP) and COLREGs. This also makes it recognizable, which means that users will understand the benefits quicker. Show that it is easy to use and useful are key for the acceptance of technology [Davis(1989)].

The type and amount of information presented to users must be tailored to the unique situation in which the information is to be used. Prior research on trust in automation found that providing human operators with information related to the reliability of an automated tool promoted more optimal reliance strategies on the tool. Further, information related to the limitations of an automated tool aids in trust recovery following errors of the automation. This added information appears to be useful in deciphering the boundary conditions under which the tools are more or less capable. Thus, providing humans with information related to the performance of an automated tool appears to be beneficial [Lyons and Havig(2014]. Therefor it is beneficial for the cooperation between manned and unmanned vessels to clearly show if it is an unmanned vessel. This will firstly be done using visible signals, and also at the start of radio communication. This also happens in industry projects like Google Duplex [Nieva(2018)].

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 design scenarios, use cases, requirements, claims, and 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 for collisions and perceived risk reduces, or at least does not increase.

Information extraction from problem scenario

In the previous chapter the problem is described which has to be solved with the envisioned technology. To solve the problem, the following issues have to be tackled:

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

Envisioned effect of system implementation

How the above mentioned problems are tackled are shortly discussed below. This shows what the result is after implementing the envisioned technology:

1. The system will send only on demand or when it has tried any other solution. This will reduce the probability for information overload. As a threshold to check if the system is successful in solving the problem of information overload, the current amount of communication can be used.
2. The protocols which are currently used by the officer of watch are the same. The purpose is to make it more easy to get information. This means that the situational awareness will minimally be affected by the system on board of the manned vessel. Also here the current level of situational awareness can be used as a threshold.
3. By introducing an negotiating agent, decisions can be made in a similar manner to current ships. Using the decision tree it will have a favorite strategy, but it might be possible to use others if this is better for the encountered manned ship. This will ensure that the officer of watch at the manned ship, still has a feeling of autonomy, similar to that of the current situation.
4. Although the current systems are not designed to be used by unmanned vessels. Are there major developments on conversational agents in the last few years. This means that voice communication is starting to become more easy to develop. Certainly when considering that a lot of radio conversations are recorded. Thus it will be more easy to train the agent. Thereby must still be considered the importance of transparent communication. Thus also being open about being a robot.
5. Using addressed AIS messages and a conversational agent at unmanned vessels. Manned ships will be able to ask for support or information at all time. It is even likely they will receive the information faster compared to manned-manned ship communication.
6. The conversational agent is most relevant for unmanned ships when they want to ask for support or information. As addressed messages are not often used at the moment. They will use the SMCP in a similar way to how it is currently used. So not much will change compared to the current situation for manned ships.

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).

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 problem is solved. Use cases are informed by human factors theories (described in the system's foundation).

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.

Rewrite introduction with purpose of these usecases

Autonomous fast crew supplier crossing shipping lane in front of cargo ship

Tags: Intention, Crossing, Messaging

A 26 meter autonomous fast crew supplier (FCS2610) is heading towards a wind farm at the north sea with a speed of 22 knots. To get there, she has to cross a busy traffic lane. There she will pass a 150 meter container ship (Reefer), sailing at 14 knots. The FCS2610 will pass in front of the Reefer with a distance of 900 meter or 0.5 Nautical mile. Which is just accepted according to the safety domains [Szlapczynski and Szlapczynska(2017b]. To ensure the Reefer understands the intentions of the FCS2610, communication is necessary. This is done in the following manner:

- The AIS, masthead and flags are showing the vessel is sailing autonomously, without interference from crew and listening to the VHF.
- A conversation is started by the FCS2610, by calling the station on board of the Reefer and updating status in AIS.

  Reefer, C-6-Z-G-7
  Reefer, C-6-Z-G-7
  This is unmanned FCS2610, 2-F-F-P-4
  Unmanned FCS2610, 2-F-F-P-4
  Switch to VHF channel seven-two
  over.

- The FCS2610 waits for a response from

  Unmanned FCS2610, 2-F-F-P-4
  This is Reefer
  Agree VHF channel seven-two
  over.

- At VHF channel 72, FCS2610 communicates her intentions.

  Reefer, C-6-Z-G-7
  This is unmanned FCS2610, 2-F-F-P-4
  Intention. I intend to pass in front with a distance of 0.5 Nautical mile.
  over.

- At VHF channel 72, Reefer confirms intention.

Unmanned FCS2610, 2-F-F-P-4
This is Reefer, C-6-Z-G-7
Intention received. You intend to pass in front. Distance is 0.5 Nautical mile.
over.

- Close communication and pass in front.

Reefer, C-6-Z-G-7
This is unmanned FCS2610, 2-F-F-P-4
Nothing more. Have a good watch.
Over.

Unmanned FCS2610
This is Reefer
Thank you.
Over and out.

- Update AIS status of FCS2610 to show it has no questions, and is listening.

Fishery vessel gets close to traffic lane with unmanned VLCC

Tags: Question

describe use case

13.3 Functional requirements and claims

In the sCE method, use cases are used to derive functional requirements and claims, i.e. specific functionalities the technology should provide to its user followed by 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. User stories are used to do this, these are usually in a from: "As an $\langle actor \rangle$, I want to $\langle what? \rangle$, so that $\langle why? \rangle$". Followed by an acceptance criteria, to determine when this part is correctly implemented.

Actors

The primary actors who will be taken into account in this first iteration are:

- Officer of watch
- Unmanned vessel
- Nearby vessel

User stories

- As an officer of watch, I want to know if there are unmanned ships in the area, so that I know if I have to adapt my way of communication. AIS shows if ship is manned, and what its status is.
- As an officer of watch, I want to validate if information received via AIS is correct, so that I can base my decision on correct information. When officer of watch asks unmanned ship via VHF, the answer should be reliable and based on current information.
- As an officer of watch, I want to make my intentions clear towards all other ships, so that they can anticipate to this. Shared intentions should be incorporated into the decision making process of unmanned ships.
- As an officer of watch, I want to be able to make small mistakes when following a protocol, so that I can still act fast when I do not know the exact SMCP sentence. The unmanned vessel should understand the message, even if its not exactly the SMCP sentence.
- As an officer of watch, I want to use existing protocols, so that the extra effort to communicate with unmanned vessels will be kept to a minimum. Current seafarers should be able to understand what they should be doing without an explanation on the protocol.
- As an unmanned vessel, I want to initiate communication, so that I can exchange information or ask questions to another specific ship. The unmanned ship needs situational awareness based on a digital model of the reality to know which ship sails where and what the interactions could be in order to make the right decision.
- As an unmanned vessel, I want to validate if acquired information is correct, so that I can base my decision on correct information. Check via communication if digital model is correct.
- As an unmanned vessel, I want to be able to check if they understand my intentions when other ships do not act as expected, so that I know if I should change my strategy. The communication should be incorporated in the decision making process and unexpected actions by others ships should be registered.
- As a nearby vessel, I want to receive only information which is relevant to me, so that the risk for information overload is limited. By switching VHF channels for full conversations this is similar to the current way of working.

add more user stories?

13.4 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. For this project they are categorized in status, messages and situations.

13.4.1 Status

By defining different states for the system, does the system know which functions and protocols should be executed. The different states are described below:

Listening Listening to the radio without taking action.

Waiting Waiting for a response by other ship.

Negotiating Deciding on the right strategy by discussing this with other ship(s).

Messaging Sending a message. While sending it is not possible to receive a message.

Updating Adjusting the information stored within the system, which will consecutively be send to others ships via AIS.

Unavailable There is a problem with the system, which makes it unable to communicate.

These states will also be communicated via AIS, to ensure transparency between different agents and avoid confusion.

13.4.2 Types of messages

Both in the messaging and negotiation states, will there be messages send. These messages form the conversation. In the different phases of the conversation, different messages will be send. These are described below:

Call Start of conversation, in which a ship only requests contact with another ship.

Acknowledge Accept invitation for conversation.

Message Starts with "marker word" to clarify communication purpose, followed by the actual message and ended by a request for confirmation. In the SMCP the following marker words are used:

- *Advice*
- *Information*
- *Warning*
- *Intention*
- *Question*
- *Instruction*
- *Request*

Response Response to the previous message in conversation.

Close End conversation with greeting.

As mentioned before the Standard Maritime Communication Phrases (SMCP) will be used, as this is a known protocol for seafarers. This protocol has its own ontology. This is described by IMO in the regulations.

13.4.3 Situation

To make the link with the decision model and problem identification as described in part II. Will the protocol use the same identifiers for situations.

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.

These situations are described in more detail in section 7.1, using path descriptions.

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.

The artefact gives a short summary of the developed protocol and its workings, together with the tool in which it can be simulated. The evaluation method will be interviews with experienced seafarers. The aim of the interviews is to answer the following question:

> *Will a protocol based on existing maritime systems and communication protocols be sufficient to ensure safe navigation while manned and unmanned vessels encounter each other?*

Different measures are used for validation and verification. Key variables are: Trust, situation awareness, effectiveness, efficiency and satisfaction. In this chapter these will be described in more detailed and what the results of the evaluation are.

14.1 Artefact

The artefact is an implementation or prototype that incorporates a given set of requirements, interaction design patterns, and technological means. This first iteration will aim at finding flaws based on expert knowledge. To acquire this a simplified prototype will be used. This means that there is no implementation using hardware which might be used in latter stages. But a simulation environment is created to test situations with experts. Where is checked if experts believe that the protocol as described in chapter 13 is sufficient to get to the right decision.

To get the right feedback, several situations will be simulated. These situations are based on the accidents as described in chapter 3, common situations around the port of Rotterdam and cases used in literature. The situations are simulated and visualized using the tool as described in chapter 5. This will enable the experts to gain situational awareness and give useful feedback on the protocol. The protocol itself is mostly knowledge based and not automated during the evaluation. Thus the interviewer has to know the Standard Maritime Communication Phrases (SMCP) and usage of systems like Automatic Identification System (AIS).

add description and printscreen of tool

add SMCP cheat-sheet

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. In this case a so-called Wizard of Oz evaluation is used. This technique enables unimplemented technology to be evaluated by using a human to simulate the response of a system. As the technology itself has not yet been implemented. The "wizard" simulates the system's responses in real-time.

Describe and reference to why tool, to cooperate at sea

14.2.1 Experiment requirements

To do the experiment, a participant is needed to have the role of Officer of Watch (OoW) and tools to execute. During the experiment there will be different variables, which have to be taken into account to be able to draw the right conclusions. These are described in this section.

Participants

The participant is in this case the Officer of Watch (OoW). The experiment will be done with at least 10 different participants. The formal requirements are as follows:

- Nationality: Dutch, due to location of experiment.
- License: Completed training as a maritime officer.
- Experience: At least 3 years of experience as seafarer.
- Attitude towards autonomous shipping: Both positive and negative.
- Age: 25-60

Tools

Beside the participants, tools are needed to do the experiment. The tools needed are:

- Laptop to show a visual of situation and show what happens during the simulation.
- Questionaire to be used before, during an after the experiment.
- Room without distractions to do the experiment.
- Recordering device to store and later process actions during the experiment.

Variables

Independent variables: SMCP Dependent variables: Trust (how to measure?), performance (right decisions), situation awareness (10 things he should have noted), effectiveness (accuraat en volledig), efficiency (inspanning en tijd) and satisfaction (prettig en comfortabel).

14.2.2 Experiment procedure

To execute the experiment. Several steps are taken together with the Officer of Watch (OoW):

1. Explain how the OoW can take actions, such as steering, change speed, set way-points or engage in communication.
2. Ask general questions on attitude and basic information.
3. Explain situation to OoW in a similar way to common hand-over. Only describe relevant issues for navigational duties.
4. Start playing simulation.

5. Depending on the simulation, let autonomous ship take actions or wait for the OoW to engage in communication.
6. End simulation.
7. Question OoW why which decision was made.
8. Question OoW on several "what if"-scenarios and how that would have changed its actions.
9. Repeat step 3-7 for more situations.
10. Describe functional design and purpose of protocol.
11. Question OoW about advantages and challenges of protocol.
12. Question OoW about human factors.

Explanation (1, 2)

The participant is not explicitly informed about the exact purpose of the research. It will however get a short introduction on how to use the tool during the simulation. It should be easy to use, as similar action should be executed when operating a vessel. Thereby is some information about the participant acquired:

- Which licenses do you have?
- What is you experience?
- What is you attitude towards unmanned and autonomous shipping?
- What do you see as the biggest challenge for introducing autonomous and unmanned vessels?

add summary of description when using the tool, reference to chapter tool

Situations and scenarios (3, 4, 5, 6, 9)

The next steps are repeated several times for the different situations. The situations which are used will be:

1. Collision between MV ARTADI and MV ST-Germain
   (A) Same decisions as reality
   (B) Do what Artadi expected
   (C) Do what St-Germain expected
2. Entering Maasgeul towards North Sea at port of Rotterdam.
   (A) Crossing in front
   (B) Crossing at the back
   (C) Passing

For these situations and scenarios, the following are described:

- Ship's position, course and speed
- Traffic density
- Weather condition and night vision
- Logbooks, checklist and daily orders

add pictures of what is exactly happening in each situations, and what possible decisions might be

Relevant questions for situation (7, 8, 9)

To gain insight into the quality of the experiment and effectiveness of the protocol, the following questions will be asked:

- Why did you do ⟨*action*⟩?
- Did the autonomous vessel act as you expected?
- Did you have the feeling, you were in control of the situation?
- Did you miss any information to choose the right strategy?
- Did you feel the urge to communicate?
- Why did you or didn't you feel the urge to communicate?
- Was the communication as you expected it to be?
- Would you have acted differently is you knew there was a human officer of watch?
- ...

Is this enough?

General questions on protocol and human factors (10, 11, 12)

After running the different situations an interview is held. This interview is intended to answer the following questions from the participant perspective and explain the purpose of this research:

- Should a protocol like this pass the turing test?
- Would you like to know beforehand if it is an unmanned vessel?
- Are horns still commonly used to show intentions?
- Did you find the protocol easy to use?
- Is the protocol useful?
- Is the protocol transparent, thus do you understand why steps are taken?
- Do you feel differently about introducing unmanned and autonomous vessels?

14.2.3 Key performance indicators

The performance indicators are similar to the human factor measures as described in section 12.2. This will be a combination of both quantitative and qualitative measurements. Thus combining numerical values with non-numerical arguments.

- Is the system used correctly?
    1. System is not understood and actions of participant are random.
    2. System is not understood, but by experience with other systems the results are good.
    3. System is understood, but does not help to get the good result.
    4. System is understood, and results are as expected.
    5. System is understood, and improves situational awareness compared to existing way of working.
- Does the protocol act as expected?
- Will it solve the problem of missing information?
- Do people perceive it as easy to use and useful?
- What is the impact on attitude towards unmanned ships?

add concrete measurement

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).

make link with variables

14.3.1 Outcomes

14.3.2 Conclusions

Part IV

Wrap-up

15 Results

Describe results when both researches are combined. Do they support each other. Relate this to the model

16 | Conclusion

16.1 Answers to research questions

16.2 Recommendations for future research

Part V

TEMPORARY: Old text

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

Abstract model

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.

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(2017a]. 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.

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.

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.

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