MSc Thesis

Improve decision making of the crew by optimizing communication between vessels

Ingmar Wever (4161041)

March 26, 2018

TU Delft DAMEN

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Project duration:	September 2017 – July 2018	
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Notes

Preface

Abstract

Glossary

Abbreviations

AIS Automatic Identification System, part of VDES

AMS Alarm Management System

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

CFD Computational Fluid Dynamics

COLREGs Convention on the International Regulations for Preventing Collisions at Sea

DOF Degrees of freedom

DP Dynamic Positioning

ECDIS Electronic Chart Display Information System

ENC Electronic Navigational Chart

GPS Global Positioning System

GT Gross Tonnage

IEC International Electrotechnical Commission

IHO International Hydrographic Organization

IMO International Maritime Organization

JIP Joint Industry Project

MARPOL International Convention for the Prevention of Pollution from Ships

SOLAS International Convention for the Safety of Life at Sea

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

TEU Twenty foot Equivalent Unit

UID User Input Device

VDES VHF Data Exchange System

VHF Very High Frequency radio

Contents

Introduction

Many people are convinced that one of the main developments within the maritime industry will be partly unmanned and autonomous shipping. A key arguments is the improved safety for seafarers, as they don't have to be on board and human mistakes are taken out. However this does not necessarily go for all other vessels around the autonomous ship. This is also where one of the main arguments against autonomous shipping comes from. How do other (manned) vessels know the intentions of autonomous vessels and can anticipate correctly to them?

Problem statement

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

To make autonomous shipping possible, autonomous vessels should know how to communicate their intentions, without overloading the VHF and AIS channels. Or a different system should be developed which than must be installed on all other vessels. In both cases should the communication be optimized. In a way that other vessels know enough about the intentions to anticipate correctly, without overloading the communication channels.

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

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

Research questions

To enable the step toward autonomous shipping, the first step is a qualitative research. Focused on avoiding the need for radio communication, by looking into which information is most relevant for the different vessels. This will be done from two perspectives within the domains of Maritime Technology and Computer Science. Resulting in two research questions:

> *How do ship characteristics influence the time-domain for decision making to ensure an unimpeded voyage?*
>
> *How to optimize the communication between vessels, to support the decision making by the officer of watch?*

Thesis structure

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

Part I

The maritime industry

1 | Current situation

Safety at sea has been a relevant topic as long as ships exist. And although the shipping industry exists for a long time, communication is where still major steps need to be taken. To ensure all seafarers get home safely.

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

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

1.1 Accidents

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

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

Are these really relevant accidents, add more?

1.1.1 MV AL ORAIQ and MV FLINTERSTAR

During the night between 5 and 6 October 2015 on the Northsea near Zeebrugge, a collision occurred between the LNG tanker AL ORAIQ, sailing under the Marshall Islands flag, and the FLINTERSTAR cargo ship, sailing under the Dutch flag. The FLINTERSTAR sank almost immediately as a result of the collision, an illustration of the accident is shown in Figure 1.1. The captain of the FLINTERSTAR was badly injured in the incident but the other ten people on board and the pilot were rescued out of the water unharmed.

Figure 1.1: Illutstration map of approximate collision location

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

1.1.2 USS FITZGERALD and MV ACX CRYSTAL

A more recent well-known collision was between the USS FITZGERALD and ACX CRYSTAL on 17th June 2017. The US destroyer hit the larger Philippines container vessel resulting in the death of 7 US Sailors. An illustration of the accident is shown in figure 1.2. According to the accident report did failures occurred on the part of leadership and watch-standers. There were failures in planning for safety, adhere basic navigational practice, execute basic watchstanding practice, proper use of available navigation tools and wrong responses.

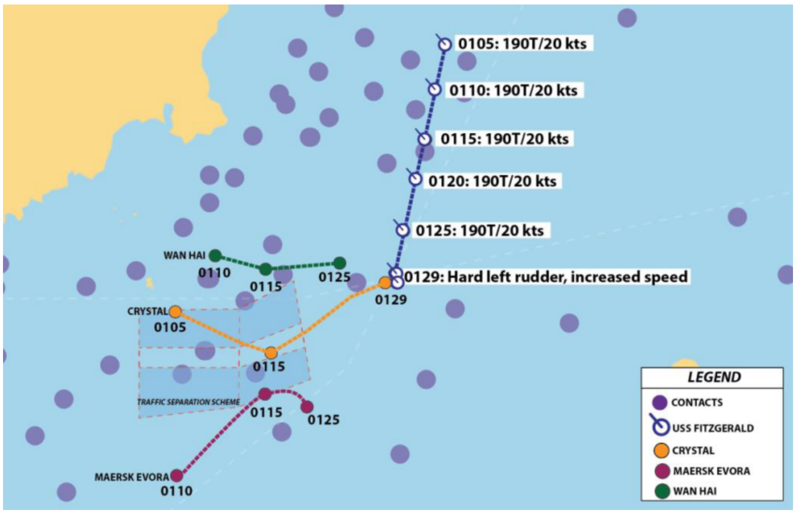

Figure 1.2: Illutstration map of approximate collision location

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

1.1.3 USS JOHN S MCCAIN and MV ALNIC MC

Even more recent is the collision between the USS JOHN S MCCAIN and ALNIC MC on 21st August 2017. The US Destroyer hit the Liberia flagged oil and chemical tanker. Resulting in the death of 10 US Sailors. An illustration of the accident is shown in figure 1.3. According to the accident report did the US Navy identify the following causes for the collision: Loss of situational awareness in response to mistakes in the operation of the USS JOHN S MCCAIN's steering and propulsion system, while in the presence of a high density of maritime traffic. Failure to follow the international nautical rules of the road, which govern the manoeuvring of vessels when risk of collision is present. Watchstanders operating the JOHN S MCCAIN's steering and propulsion systems had insufficient proficiency and knowledge of the system.

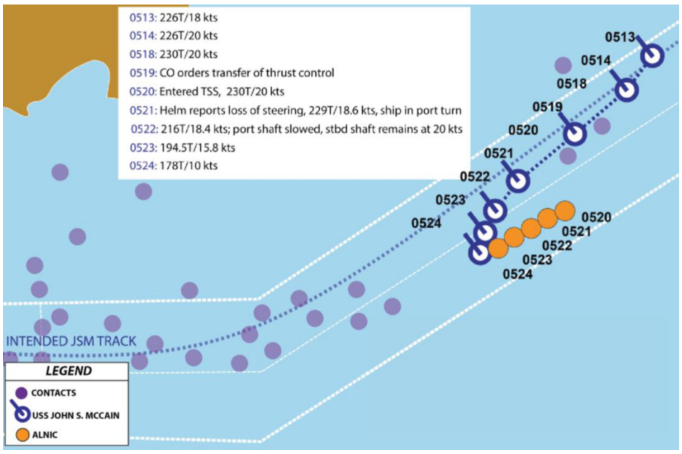

Figure 1.3: Illutstration map of approximate collision location

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

1.2 Means of communication

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

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

it this the complete list?

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

1.3 The bridge

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

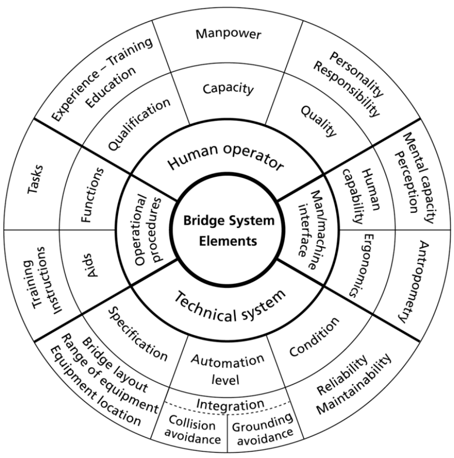

Figure 1.4: Bridge system elements

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

Is this relevant, if yes, describe different parts

1.3.1 Technical system

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

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

What do regulations say about systems which should be on board

1.3.2 Man/machine interface

How is information used

1.3.3 Procedures

Training, education and protocols

1.3.4 Human operator

How does it go in practice, experience.

2 | Future of shipping

The shipping industry is traditionally driven by regulations and making profit within these given boundaries. With small margins, this does lead to a conservative industry. On the other hand do many CEOs state that digitalization and de-carbonization are watchwords for the coming decade. Projects around this should be leading to a safer shipping industry, which becomes more efficient and at the same time reducing its environmental footprint [Eriksen(2017)], while maintaining its competitiveness. This research will mainly focus on improving safety at sea, the digitalization is most relevant here, certainly when it comes to autonomous and unmanned ships. A description will be given of the steps which will most likely be taken in the coming years, which projects are working on the steps towards the future.

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. Either remotely operated from shore, on autopilot or completely autonomous. The main arguments heard for the transition towards autonomous or unmanned ships:

- *Improved safety*, as most accidents are caused by human errors.
- *Lower cost*, as insurance goes down due to improved safety and manning is a large portion of total cost.
- *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.

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

Reference to inforgraphic with time-line unmanned/autonom levels

2.1 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. Examine the tasks in relation to a vessel's technical system and develop a concept for autonomous operation of the engine room. Define the processes in a shoreside operation center, required to enable a remote control of the vessel. Thereby taking into account the feasibility of the developed solution, including legal and liability barriers for unmanned vessels. They concluded that unmanned vessels can contribute to the aim of a more sustainable maritime transport industry. Especially in Europe, shipping companies have to deal with a demographic change within a highly competitive industry, while at the same time the rising ecological awareness exerts additional pressure on them. The autonomous ship represents a long-term, but comprehensive solution to meet these challenges, as it bears the potential to: Reduce operational expenses and environmental impact. A concept was developed for a bulker vessel, enabling the consortium to do a financial analysis. Showing the viability, but admitting the limited scope of the project [MUNIN(2016)].

2.1.1 Visionary projects

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

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

give more info on projects

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

more info on JIP

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

Make infographic

2.1.2 Industry projects

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

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

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

2.2 Other stakeholders

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

update with info from IRYOON

2.3 Possible use cases

Summarizing the projects, based on this what would be likely use cases: - Tugs as extra actuator in DP-like system
- Local transport between factories, terminals, etc.
- Crude oil tankers which are traded while at sea
- Short sea shipping (most pilots)

2.4 Changes in communication

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

2.5 Challenges when combining unmanned and manned vessel

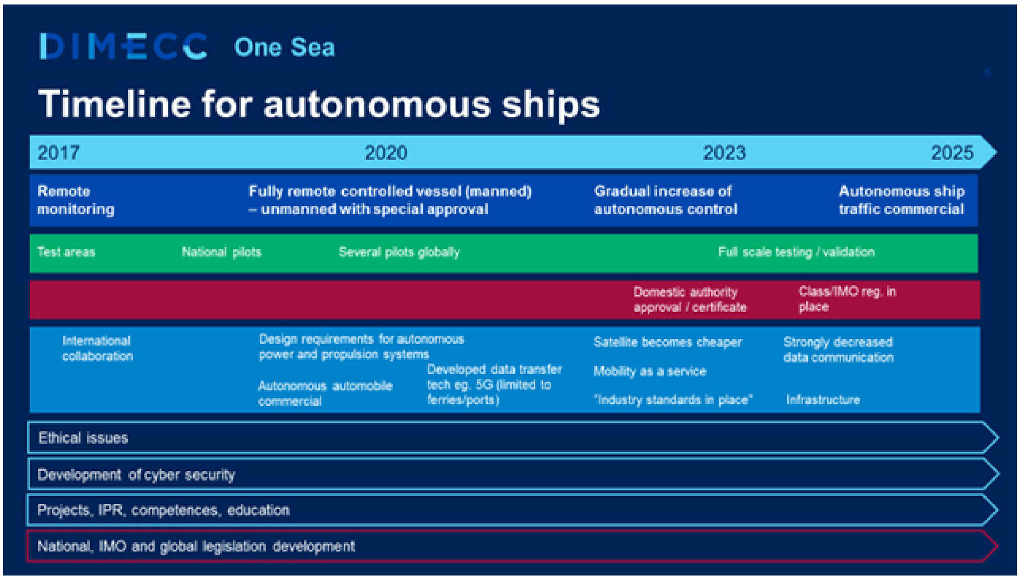

Figure 2.1: EXAMPLE-infographic: Timeline for autonomous ships by DIMECC

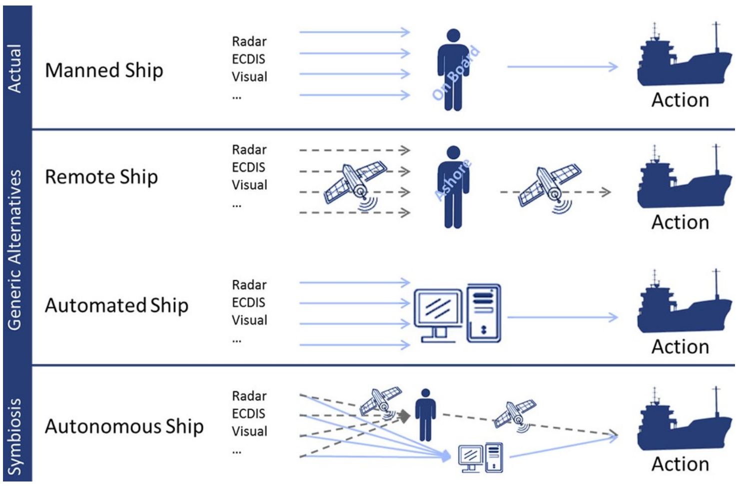

Figure 2.2: EXAMPLE-infographic: From manned to autonomous ships

Part II

Research

3 | Steps to be taken

The plans mentioned in section 2 do all have similar challenges which must be solved before autonomous vessels will set sail. One of these issues is related to the current problem already existing within the maritime industry. Situational awareness of the crew. This means getting the right information, understanding the information and making the right decision based on this. In case of navigation this often means understanding the intentions of other ships by sharing the right information.

3.1 Specific step on road map towards autonomous

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

refer to timeline infor-graphic in pre-vious chapter

3.2 Research questions

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

3.2.1 Maritime Technology

Critical situations are moments during a voyage where it is most important that is known what the intentions are of other vessels. But due to the chaotic nature of traffic situations, this is not always possible. Showing possible intentions of other vessels to the crew will enable them to acquire situational awareness faster.

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

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

3.2.2 Computer Science

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

To make autonomous shipping possible, autonomous vessels should know how to communicate their intentions, without overloading the VHF channels. The current system is certainly not flawless, as AIS is not always used correctly and in some situations Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) require 'good seamanship'. An optimization of the communication must be done, where others vessels know enough about the intentions to adapt their path to it, without overloading communication channels. This leads to the following research question:

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

3.3 Methodology

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

4 | Abstract model

As mentioned first an philosophy is developed on how to improve situational awareness by predicting the behavior. This is made understandable using an abstract model. Here is also a separation made between the relevance of the subjects for Maritime Technology and Computer Science. The reason to make this model is to have a list of topics relevant to the strategy which will be developed for the specific scenarios. In figure 4.1 a visual of the abstract model is shown. In the next section different parts of the model will be discussed in more detail.

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model in
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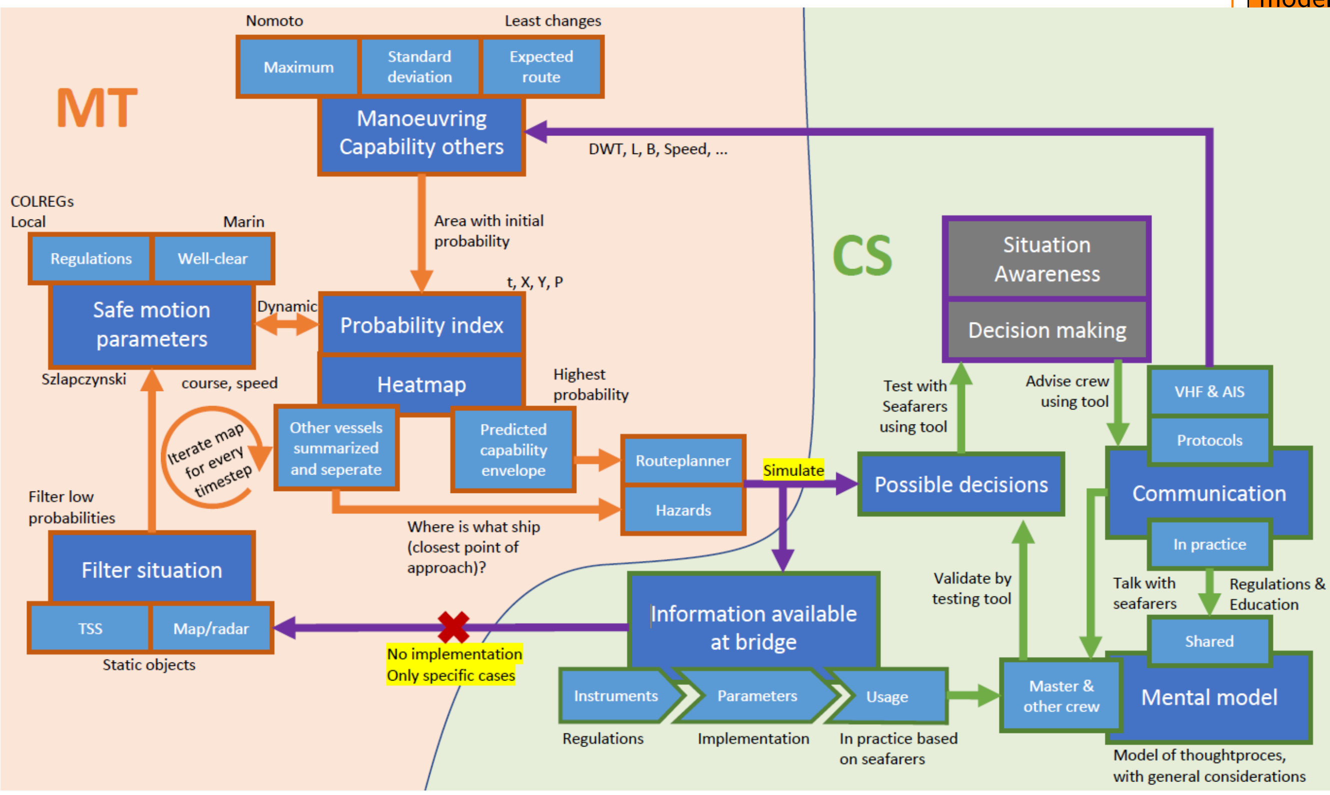

Figure 4.1: Abstract model

4.1 Ship characteristics

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

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

4.2 Influencing factors

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

4.3 Information and communication

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

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

4.4 Situational awareness

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

5 | Scenarios

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

5.1 Standard situations

To verify if the tool is working as expected, different standard situations and scenarios are tested. Which are also used to determine the thresholds to execute different strategies. The situations, scenarios and related strategies are shown in table 5.1.

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

Table 5.1: Standard scenario's

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

Make clear visualizations of scenarios

5.2 Real scenarios

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

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

Add maps of situations

Part III

Simulation

6 | Requirements

6.1 Probability index

what should the polygons show

6.2 User stories full application

6.3 User stories modules

6.4 Assumptions

7 | Building and verification

7.1 Model and classes

7.2 Methods

7.3 Estimation of characteristics

Deadweight to displacement for example

7.4 Manoeuvring capability model

7.5 Routeplanner

Including the usage of waypoints with weights

7.6 Mental model

onthologie

8 | Implementation of scenario's

Testing of the scenario's from chapter 5.

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

Part IV

Reality

9 | Validation of strategies

9.1 Are strategies realistic

9.2 Factors not taken into account

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

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

9.3 EXTEND: with more sections

10 | Validation of communication

together with seafarers

10.1 Clear intentions

10.2 Risk of information overload

10.3 Desired input

Do they want this information at the momtent

11 | Optimization of communication

what is needed to improve the knowledge on intentions

11.1 Safe motion parameters

11.2 EXTEND: with more sections

Part V

Wrap-up

12 | Results

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

13 | Conclusion

13.1 Answers to research questions

13.2 Recommendations for future research

Part VI

TEMPORARY: Old text

Introduction

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

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

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

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

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

ship characteristics:?

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

Hypothesis:

Introduction

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

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

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

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

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

Manoeuvring capability

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

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

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

IMO standard

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

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

      where L and V are expressed in m and m/s, respectively.

   (b) The value of the second overshoot angle in the 10°/10°zig-zag test should not exceed:
      i. 25°if L/V is less than 10 seconds
      ii. 40°if L/V is 30 seconds or more
      iii. (117.5 + 0.75(L/V)) degrees if L/V is between 10 and 30 seconds

   (c) The value of the first overshoot angle in the 20°/20°zig-zag test should not exceed 25°.

4. *Stopping ability*. The track reach in the full astern stopping test should not exceed 15 ship lengths. However, this value may be modified by the Administration where ships of large displacement make this criterion impracticable, but should in no case exceed 20 ship lengths.

Limits

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

Wat is constant? Versnelling/vertraging of de afgeleide daarvan

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

Desired capability

What are normal movements for a ship of a specific size

Expected route

Ship will most likely keep sailing straight and on same speed

describe formula to determine crossing-point of line

CPA calculation

Input

Nomoto, more detailed is Norrbin equation

Detailed capability

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

Prediction with limited data

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

Filter situation

Input from static objects shown on the map

COLREGs

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

Traffic separation schemes

input from local authorities

Navigational aids

map/radar/etc.

Accepted probabilities

Which probabilities can be ignored to speed-up calculation

Other filters

Significant wave height/ weather/ windspeed

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