



MSc Thesis

# Current knowledge

Model to improve situational awareness of crew

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July 17, 2018

 TU Delft

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## Abbreviations

- AIS** Automatic Identification System
- AMS** Alarm Management System
- CAM-HMI** Central Alert Management Human Machine Interface for presentaiton and handling of alerts
- DOF** Degrees of freedom
- DP** Dynamic Positioning
- ECDIS** Electronic Chart Display Information System
- ENC** Electronic Navigational Chart
- IEC** International Electrotechnical Commission
- IHO** International Hydrographic Organization
- IMO** International Maritime Organization
- MARPOL** International Convention for the Prevention of Pollution from Ships
- SOLAS** International Convention for the Safety of Life at Sea
- STCW** International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
- TEU** Twenty foot Equivalent Unit
- UID** User Input Device
- VHF** Very High Frequency radio

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# Introduction

This document will function as a starting point for my research. Summarizing current knowledge, projects and papers, which gives insight where opportunities are to create new knowledge. The main subject of the research will be: Modelling the complexity of maritime situations, to determine the probability of failure, enabling bridge systems to give a clearer advice on potential hazards and safe areas. This is used by the shipping crew to acquire situational awareness faster, compared to traditional bridge systems and raw sensors.

As described in the Dutch National Research Agenda a fundamental question we have to ask ourselves is: How do we get grip on unpredictability of complex networks and chaotic systems? Within the Netherlands Top consortium for Knowledge and Innovation (TKI) exist to support innovation by connecting companies, governmental organizations and research institutes to work together in so-called Joint Industry Projects. TKI Maritime has four main themes for these projects. This research will be related to the smart and safe sailing theme. Which aims at lowering crew and maintenance cost, while maintaining a safe working environment. Developing a system which supports the crew during navigation by adding giving more insight into the complexity of a situation, and where hazards occur. This goal is met.

This research will have two main tracks. The first part is related to the Design track of Maritime Technology. Where I will try to specify a scale for the complexity of a situation, which is correlated with the probability of failure. The second part of the research will be for the Interactive Intelligence department of computer science. Focussing on the interaction between computers and people. In this case more specific, which information does the crew currently get and what information do they need. To improve their situational awareness and make better decisions during operation.

First the relevance of this project will be shown using accidents. Followed by a description of the future of shipping in general. After that, more attention is given to the current shipping crew. Showing models to explain their behaviour and which functions they have. Followed by a detailed look at the history and future of bridge design. Including the most relevant system for this project, the manoeuvring display. At last the project plan is discussed. What should be in the last chapter of the research, which steps are taken this next year, which questions should be answered and finally what will and will not be considered.

# 1 | Reported accidents

As mentioned in the introduction is there a desire from the scientific community to do research into the topic of modeling complex systems to improve safety. But the research becomes more relevant if there is a practical application. The clearest case for non-sufficient safety measures is of an accident. Accidents have often been incentives to change or create rules. For example the leading international treaty International Convention for the Safety of Life at Sea (SOLAS). Which has been adopted in response to the TITANIC disaster. But despite new rules accidents still occur. Below some accidents are discussed and what caused them to happen.

## 1.1 TITANIC

The TITANIC disaster on 15th April 1912, is one of the most famous accidents in history, an illustration of the collision is shown in figure 1.1. Many things went wrong, which led to the death of more than 1500 people. It is known that the crew ignored warnings for ice packs and icebergs in the area, as the TITANIC did not reduce her speed. When the accident occurred, the ship was sailing almost at top speed, as the captain did not believe the ice was a serious risk to this ship. Thereby did the last minute manoeuvrer to avoid collision fail, causing more damage than a head-on collision. And after the accidents were the distress signals not received by the nearest ship, as the radio operator was off duty and they did not respond to the flares. New regulations and technologies, mitigate the risk of this happening again.

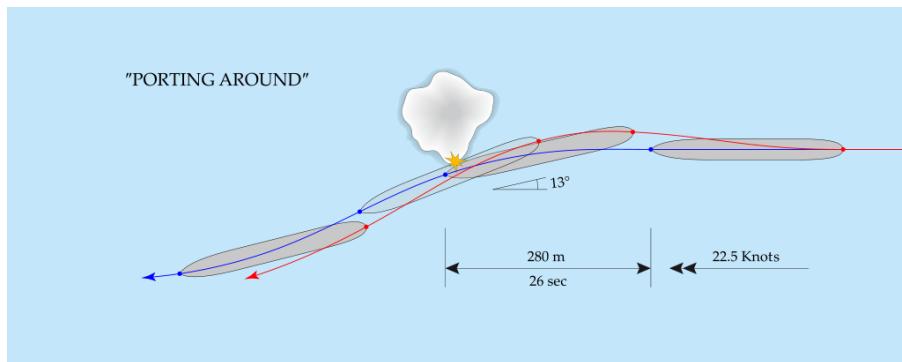


Figure 1.1: Illustration map of approximate collision location

## 1.2 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 1.2. 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 1.2: Illustration map of approximate collision location

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

## 1.3 USS FITZGERALD and 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 1.3. 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.

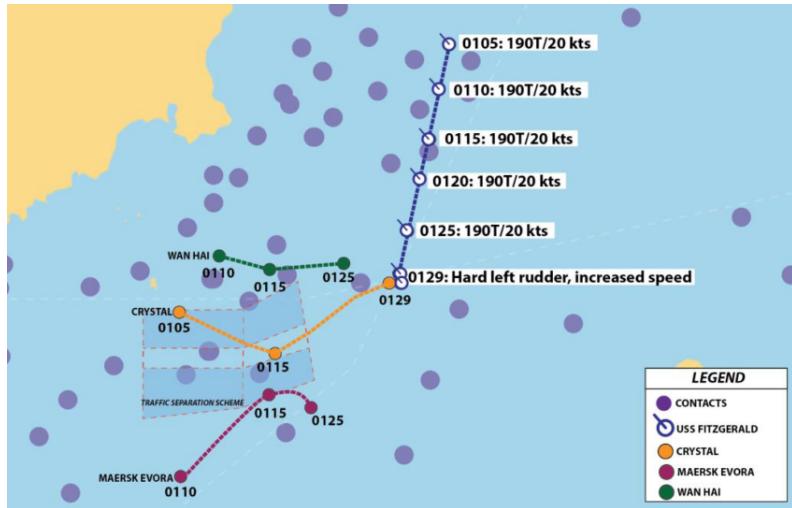


Figure 1.3: Illustration map of approximate collision location

In accordance with international rules, the USS FITZGERALD was obligated to manoeuvre 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 chose 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 manoeuvre 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)]

## 1.4 USS JOHN S MCCAIN and 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 1.4. 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.

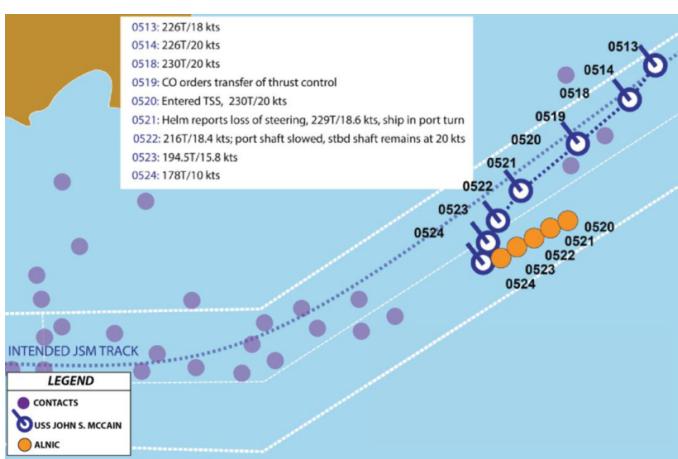


Figure 1.4: Illustration map of approximate collision location

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 they 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 sent by either ship, which are required by international rules of the nautical road. Nor was there an attempt to make contact through the VHF bridge-to-bridge communication. Many of the decisions made that led to the accident were the result of poor judgment and decision making of the commanding officer. That said, no single person bears full responsibility for this incident. The crew was unprepared for the situation in which they found themselves through a lack of preparation, ineffective command and control. Deficiencies in training and preparations for navigation were at the base of this. [US Navy(2017)]

## 2 | Future of shipping

The shipping industry is traditionally driven by regulations. 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)]. In this chapter, a description will be given of the steps which will most likely be taken in the coming years and in which projects this will be done.

### 2.1 Steps to be taken

Focussing on the digitalization, ships will become more sophisticated. More data is generated by sensors, improved connectivity and new ways to visual data. This enables ships to continuously communicate with managers and traffic controllers. At first, this can be used to analyze data and give better advice based on expected weather, fuel consumption and arrivals at bottlenecks like ports and bridges. This might result in unmanned vessels. Either remotely operated from shore, on autopilot or completely autonomous, as shown in figure 2.1. The different projects around the world follow this same path. Below some of these projects are mentioned with their current status.

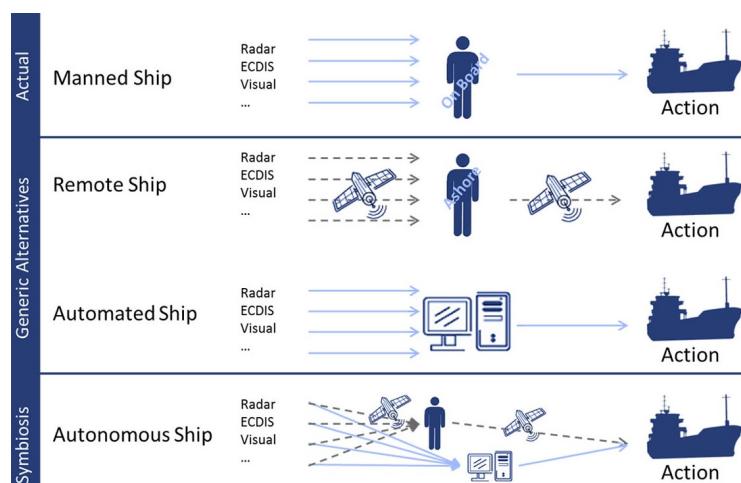


Figure 2.1: From manned to autonomous ships

The research project MUNIN consists of a consortium of shipbuilders and scientists. The name is an abbreviation for Maritime Unmanned Navigation through Intelligence in Networks. They did an initial research. Focussing on different elements of an autonomous concept: The development of an IT architecture. Analyse 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)].

## 2.2 Current industry 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. 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 it to adapt for specific routes and meet environmental requirements now, and in the future. Keeping in mind the way towards autonomous, will it have a virtual bridge, housed below the containers. Utilizing the opportunities of sensors for safe navigation, employing radar, camera, IR camera, lidar and Automatic Identification System (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, this is still in a concept phase.

Just like MUNIN did this project also originate 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. Since June 2017 is Rolls-Royce also involved in the unmanned cargo ship development alliance, which is initiated by Asian companies and classification bureaus. Many of the projects where Rolls-Royce is involved, has DNV GL also a role. But beside these projects, they are involved in other projects which look very promising.

First the projects on Norwegian ferries, which are likely to start sailing automated from 2018, just like an automated shuttle service for offshore installations. Already a step further is the Yara Birkeland, and 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, 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)].

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

# 3 | Knowledge of the crew

Seafarers are protected by international maritime treaties such as SOLAS, International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) and International Convention for the Prevention of Pollution from Ships (MARPOL). Despite the regulations does human behavior still lead to most accidents at sea. This complex multi-dimensional issue affects maritime safety and marine environmental protection. It involves the entire spectrum of human activities, performed by ships' crews, shore-based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to cooperate to address human element issues effectively [IMO(2017)]. Fortunately, a lot of research is performed around human behavior, there is thus an opportunity to keep improving the way people are involved. And their capabilities are utilized while mitigating their vulnerabilities. This chapter will discuss research on situational awareness, how this impacts the crew, what crew there is and how they can be supported.

## 3.1 Situation awareness

Experience is key to improve the skill to scan for hazards. This is known as the situational awareness [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 3.1), the three levels are [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.

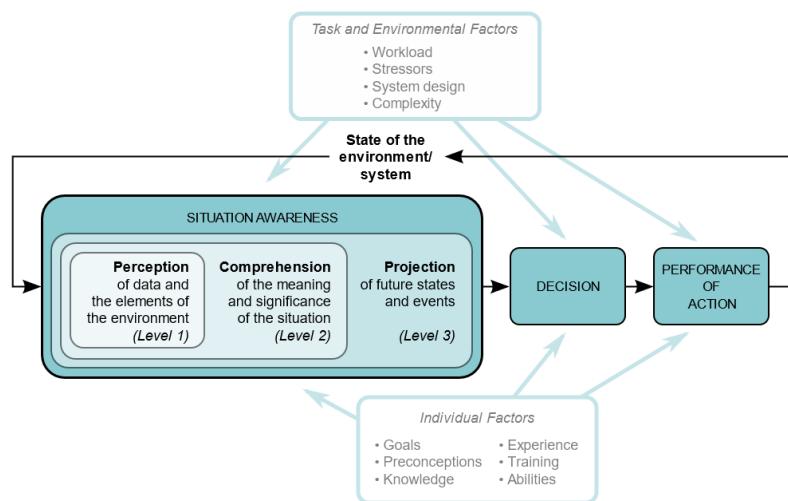


Figure 3.1: Endsley model for Situation awareness

## 3.2 Mental model

To explain why someone predicts a future state that will occur, it is important to get insight to the mental model of the crew. The mental model is the mechanism which describes elements in the environment within a volume of space and time. Giving explanations of system functioning, observed system states, and predictions of future system states. Done for a specific representation of the real system, for only selected concepts and relationships [Kalloniatis et al.(2017)]. The selected concepts and relationships are based on the background of the person. This is the reason why an economist and an engineer will have completely different mental models when looking at a ship. Where the economist sees it as an investment with related cost and returns. Will the engineer focus more on the way how it sails, propels itself and stays upright. The focus of the crew will be on the state of the vessel and the environment. Does the machinery work, what is the operational status of the vessel, what is the speed of the vessel, what is the wind and current speed, will they encounter bad weather, are there other vessels, does the vessel follow the planned route, etc. This means that a well-designed bridge and a high-quality planning are needed, to be able to understand the risks and know which information is desired when. When this does not happen loss of situation awareness occurs. This is according to Sandhåland, based on accidents at the north sea caused by: inadequate design, planning failure, communications failure, distracting elements and insufficient training. The consequences have been a failure in monitoring the vessels status. For example, if the steering was on auto-pilot or manual, detecting obstacles during bad visibility, or not receiving the right thruster status. In some cases, it went a level deeper in situation awareness, where the crew received the information. But did not make the right decisions based on this. This was often because the crew was not aware of the risk involved and the effect of operating with the system configured in a specific way. For example, when a thruster was deselected, redundancy was lowered, which finally led to the accident. [Sandhåland et al.(2015)].

When the crew was not aware of the risk involved, they had a wrong mental model of the system. The best way to improve someone's mental model is by training. This training is mostly focussed on acquiring experience in specific situations. The decision process in these situations is often dynamic, biased by individual perspective and goals, conditioned by previous experiences, including many system components and nonlinear relationships. This is also why it is hard to learn from normal data sources such as books or video. But experience has to be acquired to store situations directly in the mental model of the crew. Consequently, failures and conflicts are needed to improve these processes. As they show boundaries for decision making. This can be done using scenario-based training environments using virtual reality. It has been shown that training in those environments will lower stress and enhance professional performance in real-life situations [Ford and Sterman(1998) [Cohen et al.(2016)].

### 3.3 Shipping crew

Already some roles within the shipping crew were mentioned. But to give more insight here is a summary of the different roles on board of a merchant's vessel. At smaller vessels, roles are combined where possible. The Navy has in some cases even more operational crew members. In figure 3.2 the structure is shown for officers. 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)]

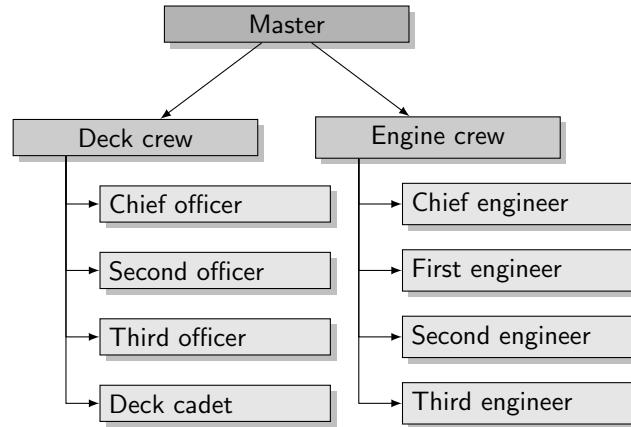


Figure 3.2: Crew structure basic

#### 3.3.1 Deck crew

The Deck crew is 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.

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)]

### **3.3.2 Engine crew**

The engine crew is responsible for operating, maintaining and repairing, the propulsion and support system. The engine department is also responsible with the repair and maintenance of other systems, such as: lighting, lubrication, refrigeration, air conditioning, separation, fuel oil, electrical power and so on. According to the vessel's hierarchy, the engine officers are as follows: Chief Engineer, Second Engineer, Engine Watch Officer, Electrician Officer and Engine Cadet.

The first engine officer and in charge of the engine department is the Chief Engineer. He takes complete control of the engine room and must make sure that every system and equipment runs by the book and is suitable for inspection at all times. The Chief Engineer also maintains up to date inventory for spare parts, extra fuel and oil and delegates the tasks for the officers under his command. In order to become a Chief Engineer, a seafarer must first be a Second Engineer with at least two years sea time experience. After the Chief Engineer, in charge with the engine room is the Second Engineer, who also has a management level position. He assists the Chief Engineer in keeping the vessel running efficiently, is responsible for supervising the daily maintenance and operation of the engine room and prepares the engine room for arrival, departure or other operations. He reports directly to the Chief Engineer. The Engine Watch Officer position is usually held by the Third or Fourth Engineer and it is an operational level job. The Third Engineer is usually responsible for the change of boilers, fuel, the auxiliary engines, condensate and feed systems. The Fourth Engineer is the most inexperienced officer, who has duties assigned by the Second Engineer, and some of his responsibilities are: engine watch, air compressors, purifiers and other auxiliary machinery. Another officer working in the engine room is the Electrical Engineer, in charge of overseeing and ensuring the maintenance and proper functioning of all the electrical systems and machinery. The Electrical Engineer responds directly to the Second Engineer and to the Chief Officer and has to have the proper training to do this job.

Some merchant vessels also have amongst its crew members an Engine Cadet or Electrical Cadet, who receive structured training and experience on board and learn how to become an engine or electrical officer. Apart from the officers, the engine department crew also consists of ratings, such as Motorman, Fitter, Electrician, Pumpman and Oiler/wiper. The Motorman is the engine rating who keeps watch and assists the engine officers when performing maintenance tasks. He also participates in maintaining and repairing the main and auxiliary engines, pumps and boilers. On board vessels, the Fitter carries out daily maintenance and engine cleaning jobs and is also specialized in fabrication, welding or repairing. The Electrician on board a merchant's vessel is the rating working on the electrical equipment and systems, wiring and high voltage panels. Mostly on tanker vessels, we may also find a Pumpman, responsible with the liquid cargo transfer system, pumps, the stripping pumps, filters valves, deck machinery involved in the liquid cargo transfer etc. His main job is to keep the liquid cargo system on a tanker running accordingly. The Oiler or Wiper on board is the rating in charge with cleaning the engine spaces, machinery, lubricating bearings and other moving parts of the engine and assisting the engine officers in the general maintenance of the machinery in order to ensure the oil temperature is within standards and oil gauges are working properly. Although the crew structure in the engine room is mainly the same, there are vessels that only have a part of the mentioned crew. This is due either to the size of the vessel or to financial reasons. [Nedcon(2013)]

### **3.4 Crew support**

All the different crew members have their responsibilities. In the short term, this won't change. Therefore this research will mostly focus on supporting the current crew. The focus is navigation and communication, where acquiring situational awareness is most important. Therefore all different members of the deck crew will be considered. As these crew members depend on developments and would use a decision support system to improve situation awareness. Thereby will be considered which behavior does currently often lead to incidents and how this can be improved. There is most likely a difference between stressful situations and a controlled environment. This will be taken into account during the tests. Also the impact of regulations on these extra systems will be considered. As some of the regulations may have secondary reasons. For example is the loss of manual control skills due to automation is a serious concern in the highly automated aviation industries. Automation not only results in loss of psychomotor dexterity but also degradation of the cognitive skills required to accomplish the task successfully, especially in emergency situations [Saffarian et al.(2012)].

# 4 | The bridge

In section 3 is discussed, how situation awareness is created by monitoring the vessel. The crew monitors the vessel from the bridge. The development of the bridge design is driven by technological advancement and regulatory demands. Which has increased the amount of equipment on a ship's bridge. Leading to all different components giving more and more data. As described by Speier are nowadays new technologies the primary reason for information overload. Not only because it produces more data, more quickly. But also that this information is disseminated more easily to people who do not need it [Speier et al.(1999)]. This chapter goes a level deeper than the previous one. The focus is on the crew at the bridge, what instruments and equipment there is, how the bridge developed and might develop in the future. The chapter will be concluded with a part on the manoeuvring display which is most relevant for this research.

## 4.1 User stories crew

To get insight into what the crew does on board of the ship, and which functions are desired. Different user stories will be written. In section 3.3.1 the different deck crew members with their responsibilities are already described. A user story has as main goal to define a measurable function. It might replace a list of requirements. The main focus is who, what and why. Not how it should be implemented or developed. Examples of these user stories related to the tool and model can be:

- As a master I want to see within a few seconds if there are hazards, so that I can decide if I should pay extra attention.
- As a crew member I want to have a guarantee that I know about all hazards, so that I can make the right decision.
- As a navigator I want to be able to see the consequences of a decision, so that I can make the right consideration for future decisions.
- As a master I want to get extra information on relative speed and possible place of colliding, so that I can judge myself if there is a high risk.
- As a master I want to be able to communicate an explanation for our current status and the decisions we made, to port authorities, nearby vessels and other crew members, so that there is a shared mental model.

During the project, a list of these user stories will be formed, also based on conversations with crew members. Beside this, the different steps in the thought process should be mapped. Together with the user stories, this can be used to develop a good mental model of the different crew members. Thereby will I also try to consider communication between authorities, other vessels, pilots and within the ship during hand-overs.

During this process, there will be three categories of information: relevant information, unused information, missing information. The unused information might lead to information overload. As Sandhaland already mentioned how information overload is one of the main reasons for loss of situation awareness. During the previously mentioned accidents was the desired information available. It was however, not interpreted correctly by the crew.

## 4.2 Bridge elements

The bridge of a vessel has four elements according to DNV-GL. The human operator, procedures, technical system and the human-machine interface. The safe operation of the vessel can only be assured when these are aligned. In figure 4.1 the different elements and their key factors are shown. Regulations aim to regulate these factors to ensure a safe performance of the bridge system to ensure system reliability in various modes of operation under different operating conditions. [DNV GL(2011)]

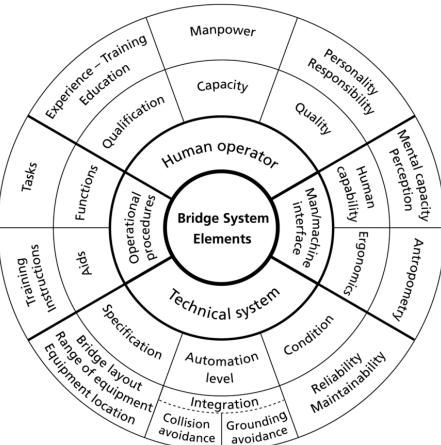


Figure 4.1: Bridge system elements

## 4.3 Instruments and equipment

Depending on the different station at the bridge certain equipment must be installed and within reach. But at least the following instruments and equipment shall be installed: navigation radar with radar, propulsion control, manual steering device (with take-over), heading control, 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 User Input Device (UID)s, general alarm control, window wiper and wash controls, control of dimmers for indicators and displays, steering UIDs, propulsion, emergency stop for propulsion machinery, gyrocompass selector switch and steering gear pumps.

These different systems have indicators with information on: propeller revolution, speed over ground, windspeed and direction, rudder angle, rate-of-turn, heading, steering mode, steering position in command, depth indicator, clock, Central Alert Management Human Machine Interface for presentation and handling of alerts (CAM-HMI), alarm panel related to unmanned machinery space, alarm panel related to steering control system and steering gear, sound reception display and warning of surveillance period elapsing.

Depending on the vessel some extra instruments can be for track control, steering control station selection, thruster UID and emergency stop for thrusters. Which give information on the thrust, pitch and when provided a conning information display [DNV GL(2017)]. Different examples of bridge designs can be found in figure 4.2.

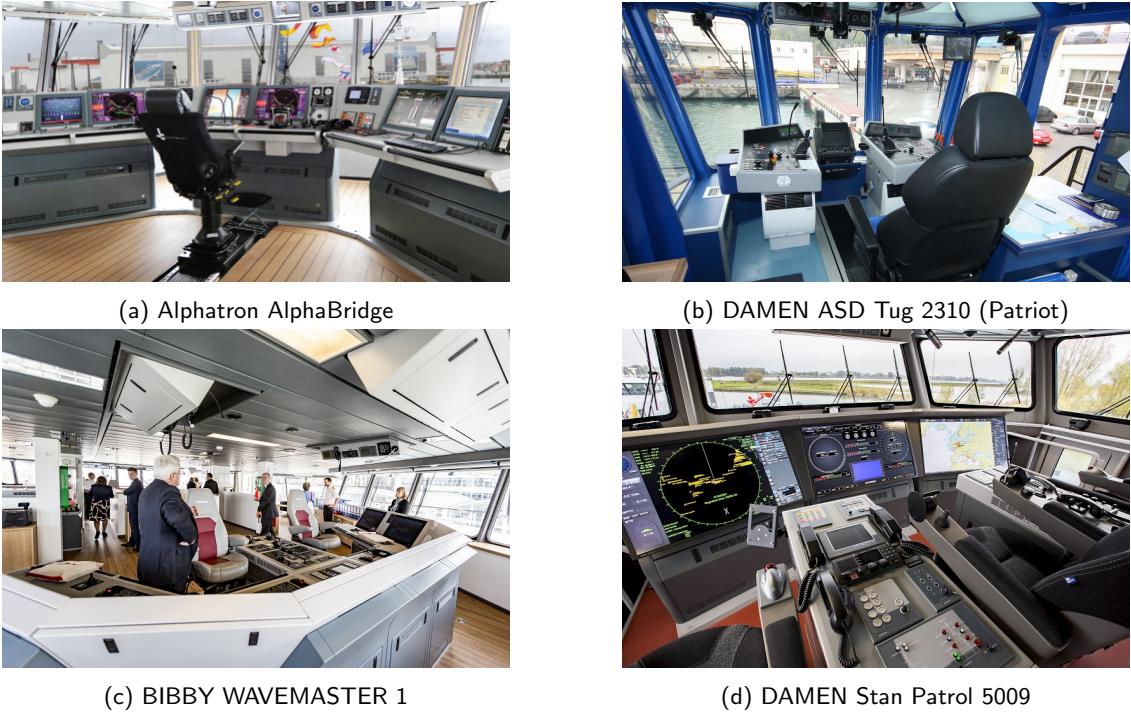


Figure 4.2: Various examples of bridge designs

## 4.4 History of bridge design

A brief history of bridge design starts at the transition from sailing ships to paddle steamers in the 19th century. Where the captain's sight could not be obstructed by the paddle houses, and engineers needed a platform from which they could inspect the paddle wheels. A raised walkway was created between both paddle houses, literally a bridge. The name bridge stuck, even when ships started using screw propellers. From the bridge, commands were passed via officers to the different stations. Where physical actions were carried out to control the ship. As technology did not exist to remotely control the ship. The helmsman or coxswain operated the ship's wheel from the enclosed wheelhouse, and engineers received commands in the engine room via engine order telegraphs. Where the bridge was often open to the elements, a weatherproof pilot house could be provided, from which the navigation officer could issue commands.

With the development of steel ship, came also the requirement of a compass platform. Sited as far away as possible from ferrous interference. Later this was solved with a binnacle. But this was another system which was introduced. In modern vessels, most of the stations for physical control have been moved to the bridge. The rudder and throttle can be operated directly from the bridge. Due to previous accidents, it is even common to have unmanned machinery spaces during operation in smaller ships. The technological developments have also lead to a variety of systems as mentioned above. Starting with radar at the start of the 20th century. ECDIS was another major step forward, where it was accepted in 1995 by IMO as an up-to-date chart as required by SOLAS. Later made mandatory in 2009 by SOLAS, where STCW requires ECDIS competence for navigational officers and masters. This added an extra screen. Continuously adding other instruments for meteo, AIS, echo sounder, different compasses, etc. First, the different instruments had all a separate analog instrument. Nowadays these are often displayed together at the conning display. While having the separate instruments at less convenient places.

## **4.5 Future of bridge design**

This conning display already gave the opportunity to develop a more user oriented-bridge environment. But with the continuous development of different sensors. A new revolution is coming for bridge design using among others: sensor fusion, new ways of visualization and decision support. These are known as integrated bridge systems. The development of future bridge designs goes parallel to the research into autonomous vessels. Both can be traced back to the changes in philosophy on human-computer interaction. Below some of the concepts are explained where often a combination of classification societies, research institutes, and commercial companies are involved.

### **4.5.1 Concept designs**

Within Damen, there is the desire to make the bridge design more standard and create more of a brand identity. An integrated design is desired in this case, where suppliers deliver the back-end. Similar projects which already show a future vision of ship design are the Ulstein Bridge Vision concept and Rolls Royce oX bridge. Where augmented reality in the windows and adapting user interfaces are key. With early warnings, decision support for economic sailing, environmental analysis, and having the ability to use the windows as a screen to simulate operations. While it is clear that here lies the future of bridge design, they did not yet come with clear solutions. Although in projects like Waterborne some steps are made when it comes to the user interface.[Rolls-Royce(2015)] [Ulstein(2013)]

### **4.5.2 Research projects**

The CASCADe project has already been more research-oriented and towards a practical solution. They have tried to develop a bridge system which adapts displayed content on the user interfaces to the current situation, relevant procedures and the needs of the crew. Using a virtual simulation platform which enables analysis of the cooperative bridge system purely based on models, in particular, Cognitive Seafarer Models which mimic decision making and situation awareness processes of real human seafarers. The virtual platform allows a very careful evaluation of the Adaptive Bridge System to research solutions for adaptation which provide benefits (e.g., increase situation awareness) that outweigh their costs (e.g. cognitive disruption).[CASCADe(2015)] Within Damen there has been research on bridge design by Myrthe Lamme. She looked into the development of an identifiable, integrated, and user-focused bridge concept. She did this from an industrial design perspective. Her focus kept in mind the current information, and how this can be presented. But did not really look into presenting different information on hazards for example.

### **4.5.3 Suppliers**

But currently bridges are already built and the companies developing these are also not standing still. But present more realistic their current status. The Kongsberg K-Master work environment integrates already different systems in one user interface. Dynamic positioning, manual propulsion and thruster control, alarm monitoring and remote control of machinery, central bridge alarm system, the operation of auxiliary bridge systems and chart, radar, autopilot and conning displays are all combined. Where this system was originally only for the aft bridge, is it now used for a variety of vessels. [Kongsberg(2017)] Many of the Damen vessels are making the step towards integrated bridge systems, which is the next step in a more user-centered design. Examples are, Praxis' Mega-Guard IBS or Alphatron's AlphaBridge. On a single screen Radar, ECDIS, conning, alarms, other ship systems and AIS can be combined. Other major players in the development of integrated bridge designs are Sperry Marine, Raytheon Anschütz and Admarel.

## 4.6 Manoeuvring display

The CASCADe project already showed the advantages of an adaptive bridge system. This is among other things done by creating an overlay in the ECDIS. Which is a geographic information system used for nautical navigation. It displays information from Electronic Navigational Chart (ENC). And integrates position information, heading and speed through water. Possibly add radar and AIS information. Using alarms when the vessel gets in proximity to hazards.

For this project, an overlay will be created to the ECDIS. Which improves the current alarm system. Using a white box approach in the model will help to define alarms and mark forbidden zones. Which forms the overlay for the ECDIS. Thereby need to be taken into account, the rules and regulations for the ECDIS system as defined by the International Hydrographic Organization (IHO) and International Electrotechnical Commission (IEC) based on International Maritime Organization (IMO) resolutions. Three important standards are IEC 61924-2:2012, IEC 61174:2015 and IEC 62065:2014. The first specifies the minimum requirements for the design, manufacture, integration, methods of testing and required test results for an integrated navigation system. The second specifies the performance requirements, methods of testing and required test results of the ECDIS. The third specifies the minimum requirements for track control systems, including alarms and warnings. To understand how this information can be added, more information on the backend is needed. The IHO standard for ENC datasets is S-57. Which normally have a .000 extension. Update files for the ENC have extensions like .001, .002 and so on. It has information on every object. In general information on the publisher of the ENC, informational text, scale to display. Further information depends on the object, objects can be landmarks, coastguard stations, cables, beacons and other types [IHO(2017)]. Depending on the ECDIS there are different ways to add the overlay. OpenCPN is a free open-source chart plotter and GPS navigation software program (figure 4.3). Which is developed by active sailors using real-world conditions for program testing and refinement. Other options could be to develop a plug-in for existing systems from suppliers of Damen, or the system used by Marin.

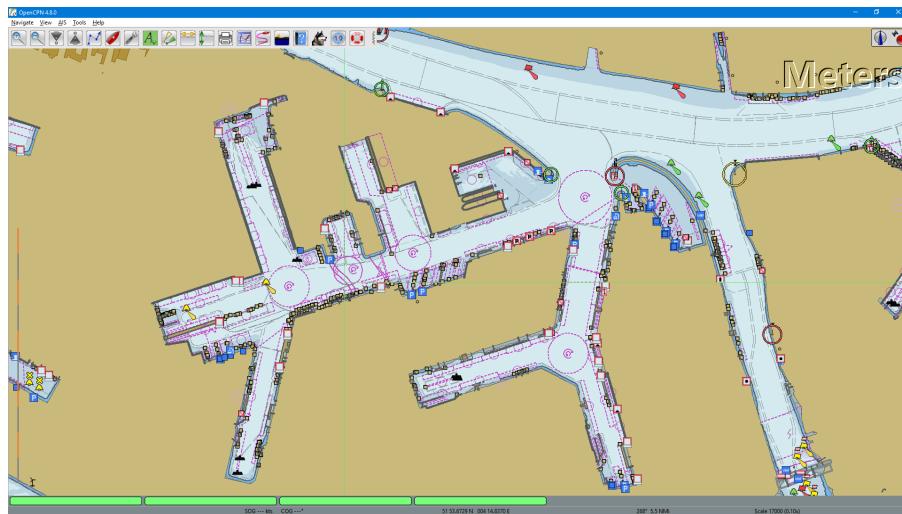


Figure 4.3: OpenCPN print-screen

# 5 | Model

For the maritime technology part of the research a model will be developed incorporating different steps to determine the hazards and probability of failure. Ultimately this should lead to safe decision making by the crew. To get here different steps are taken, as shown in

## 5.1 Physical models

### 5.1.1 Manoeuvrability

How does the inertia of ship work, and movements due to props and rudder.

Abkowitz defined in 1964 a simple model where position (X, Y) and rotation (N) depends on speed, acceleration and rudder angles. Including hydrodynamic forces and moments. This is needed to calculate the path.

### 5.1.2 Environmental forces

How are we going to model the wind, wave and current forces

## 5.2 Route planning

What are key issues in optimizing the route Model predictive control - Tor Arne Johansen

## 5.3 Cost function

## 5.4 Monitoring

### 5.4.1 Ship

### 5.4.2 Environment

what is the consequence if there is no AIS available, which other methods are there to warn for hazards like that?

- well-clear is also based on good seamanship, slow down when there is a difficult situation ahead

notes to <https://www.youtube.com/watch?v=zsxQUzBinLc> Safe passage of Singapore strait - COLREG 19,20 and 35 - basic visibility - COLREGs 6 visibility, sea room, traffic density

which rules do apply effect of traffic separation scheme (TSS)

User stories: look well ahead request information VTIS and what is VTIS good practice to inform VTIS of entering a zone navigational advice from VTIS not leading - it's important to have a system which shows if ship is doing what is discussed. Destination in AIS is not always correct. Determine what would be logical and do they follow this path, if something strange happens. Immediate warning and increase of probability. SMS specifies manning, also for watchkeeping IALA Buoyage system says what buoy says what <https://www.navcen.uscg.gov/?pageName=AISMessage21>

# 6 | Project plan

Based on the insight acquired from the previous chapters a plan of approach can be made for the next steps within my research. This will eventually lead to a desired result and a timeline towards this goal. With a summary how this is positioned within the scientific landscape and the key resources.

## 6.1 Desired result

With the knowledge from the previous chapters a framework can be formed for my research. Hereby taken into account what has already been done and how this can be used. Although the research consists of two parts. The first part is for the department of Maritime Technology and Transport. The second part of the research will be for the Interactive Intelligence department of computer science. Will the result incorporate the conclusions of both parts, resulting in a single adaption to the bridge system.

This adaption will show the complexity of a situation, which is correlated with the probability of failure. Using a white box approach the hazards. Will there be an overlay for a navigational chart, showing areas with increased risk and an advised sailing route, using different colors. Beside this overlay a list of advised actions will be presented, including the desired operations and communication.

## 6.2 Timeline

The project is meant to be a full study year, thus 60 ECTS. To have some idea if the project is on schedule, multiple deadlines are set. The planning including these deadlines is presented in table 6.1. This timeline is a rough idea and may be changed during the project depending on new insights or new opportunities.

Table 6.1: Timeline

Beschrijving	Start	Deadline
Project plan met initiele planning		6 okt
Samenvatting gerelateerde projecten en onderzoeken	4 okt	20 okt
Plan van aanpak met opzet voor rapport	9 okt	3 nov
Inlezen in papers en projecten en vertalen naar current knowledge	20 okt	19 nov
Definieer well-clear op basis van regulations en company policy	1 nov	19 nov
Plan van aanpak definitief maken	20 nov	26 nov
Programma van eisen voor tool opstellen en test voor CS	26 nov	17 dec
Onderzoek naar cost functie en modellen benodigd vanuit MT perspectief	17 dec	10 feb
Opzet voor onderzoek met crew	5 feb	10 feb
Ontwikkelen van GUI en tool op basis van programma van eisen	12 feb	5 mar
Testen met crew	5 mar	2 apr
Tool verbeteren op plekken waar meer detail nodig is	19 mar	6 apr
Opnieuw testen en vergelijken met eerdere tests	2 apr	13 apr
Vergelijking maken tussen theorie en praktijk	16 apr	30 apr
Rapport CS en MT finaliseren	30 apr	4 jun
Artikel schrijven	4 jun	29 jun
Presentatie	24 jun	6 jul

## 6.3 Research questions

Using the information gathered in the previous chapters, a step can be made towards a clear definition of the thesis statement. The initial starting point is written down as an open question. This is done for both the maritime technology part and the computer science part:

### *Maritime Technology*

How will insight into the probability of failure and complexity of a situation, help to determine the well-clear condition for different ship types and situations, which improves the advise on potential hazards and safe area's by bridge systems?

### *Computer Science*

Why does the shipping crew acquire situational awareness faster, when receiving information on potential hazards and safe sailing area's, instead of only using traditional bridge sensors?

Beside these main questions, other questions have to be answered to give a well founded answer on the main questions. Those questions can be answered using literature, interviews, but in some cases are models developed, which might be used in the final model. These questions will be the basis for the reports.

- What is needed to create situation awareness?
- What information is available at the bridge?
- Which information is available through authorities?
- Which information is shared and communicated between different vessels?
- How can this information be stored and used in the model?
- What are in general the possible choices of the crew?
- What is the probability that certain choices are made?
- What is done well while supporting navigation?
- Where are mistakes made during navigation?
- How are regulations influencing the development of safer bridge systems?
- What determines the manoeuvrability of a ship and can this be classified using estimations?
- What is the uncertainty of the physical models?
- Which information should be visualized?

## 6.4 Scope

Due to the time limits and the way this project is set-up. Not everything will be taken into account. The focus will be to improve the availability of information on hazards and safe area's. Developing a model providing the information, and developing a tool to present the information.

### 6.4.1 Model

The overlay for the chart system is based on the model for complexity. To determine the complexity certain steps are taken. In those steps some parts are assumed. General assumptions are a 3 Degrees of freedom (DOF) system, no shallow water, no ship-ship or ship-bank interaction and no extreme movements. This is done to simplify the calculations. Beside these assumptions, during the different phases the model goes through, assumptions will be made too.

1. *Determine future locations after a number of time intervals:*

For every dynamic object tracks are calculated. The current speed through water is used, later this can be extended with the acceleration. For every rudder angle the rate of turn is determined and thus the change of heading. On every track the speed and change of heading is kept constant. A normal distribution for the chosen rudder angle is used, to calculate if a certain track is chosen, as the least amount of change is desired. Manoeuvrability estimations are needed for the different dynamic objects.

2. *Find collision points, based on tracks*

Based on the tracks, a probability for collision at a certain point can be determined. Depending on the current situation, the well-clear distance can be set.

3. *Determine how hard it is to avoid collision:*

This is done by changing speed. Data on inertia of object is needed. Most efficient when least amount of changes are made. The first iteration will focus on avoidance, not taking into account to get back on track, nor zigzagging or other extreme movements.

4. *Update probabilities:*

Using information from collision avoidance system and regulations.

5. *Determine safe area:*

Subtracting forbidden area's, risk area's. If circles are used, the advised route is perpendicular with that circle.

### 6.4.2 Tool

The tool which uses the information from the model will have the overlay function. This tool will be developed for the crew, whom are directly responsible for navigation. Usually this is the captain. Therefore he will be the main focus during the first iterative step. Before setting the exact scope of this part, the impact and tasks of the captain have to be mapped.

### 6.4.3 Chosen vessels and situations

The tool will be tested for ships of different sizes, this is done to get insight in the effect of manoeuvrability. For now three ships are chosen where much data is available for, their characteristics are shown below and photos in figure 6.1:

Name	BIBBY WAVEMASTER 1
Type	Service Operations Vessel
Length o.a.	90.00 m
Beam mld.	20.00 m
Design draught	4.80 m
Deadweight	2400 t
Speed	13 kn

Name	DAMEN ASD 2810
Type	Tug
Length o.a.	28.67 m
Beam mld.	10.34 m
Design draught	4.72 m
Deadweight	531 t
Speed	13.8 kn

Name	KRISO Very Large Crude Carrier 2
Type	Academic standard model oil tanker
Length o.a.	320.0 m
Beam mld.	58.0 m
Design draught	20.8 m
Deadweight	320438 ton
Speed	7.97 kn

Other vessels which do occur in the different situations are classified according to navigational regulations, their size and displacement. The list with these types of vessels will be defined later in the project. Combined with more relevant characteristics for the previously mentioned vessels.

For the analysis different situations will be tested. Together with Marin can be discussed which are relevant. The collision between the FLINTERSTAR and AL ORAIQ is a good example, other situations might also be based on previous accidents.



(a) BIBBY WAVEMASTER 1



(b) DAMEN ASD Tug 2810



(c) SIRIUS STAR

Figure 6.1: Vessel to be used

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