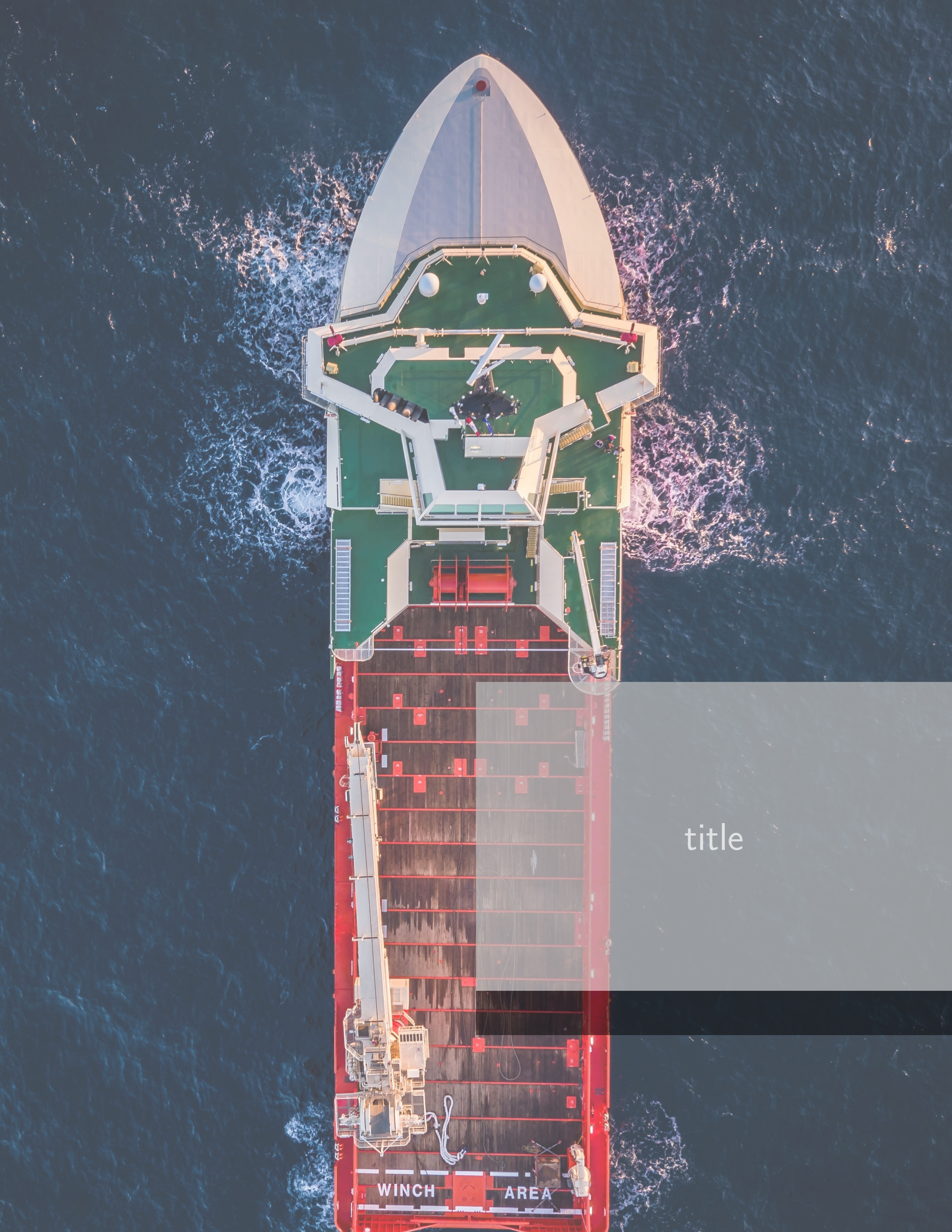

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MSc Thesis - Current Knowledge

Model for the complexity of maritime operations

Ingmar Wever (4161041)

November 22, 2017

Notes

Contents

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

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

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 advise on potential hazards and safe area's. 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 projects will be described who are the frontiers and which are seen as the future of shipping. After that, a literature review is done on subjects like situation awareness, decision making, and mental models. This will be the foundation of the research for computer science. Followed by a research into the physical world of the ship, why does it behave like it does, and which forces work on the ship. Using this information a model will be created where also route-planning and collision avoidance are discussed. Information on how information for the model is acquired is the next important step. The model should finally lead to a cost function and this will be presented to the crew. At last, a discussion about the scope is being presented to really demarcate where my research will focus on and what potential iterative steps are. Check if this is really the structure

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 adapt rules. For example the leading international treaty for safety of life at sea (International Convention for the Safety of Life at Sea (SOLAS)) has been adopted in response to the TITANIC disaster. But despite new rules, still occur. Below some accidents are discussed and what caused them to happen.

1.1 TITANIC

The TITANIC disaster on 15th April 1912, is on of the most famous accidents in history, an illustation 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 ice bergs 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. But still the human factor led to many accidents.

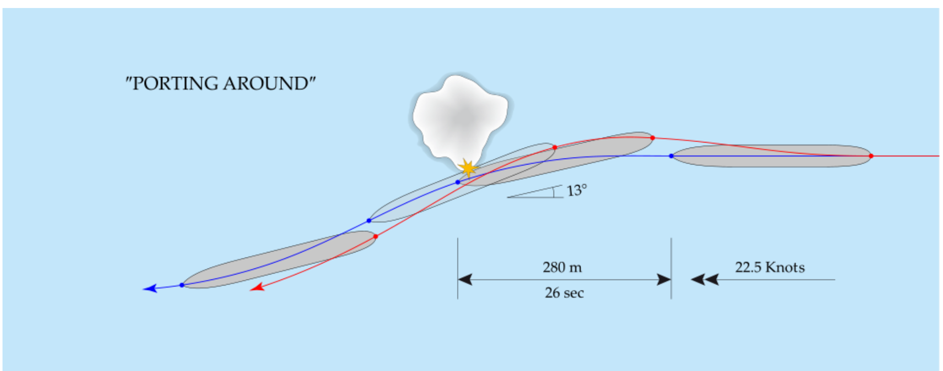

Figure 1.1: Illutstration map of approximate collision location

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: 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 starboard side. On board of AL ORAIQ were coastal pilots witch did not receive feedback from the watch keeping team, 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 asses the situation properly, leading to very little situation 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 the bridge watch keeping team 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 consistent 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 watch standing practice, proper use of available navigation tools and wrong responses.

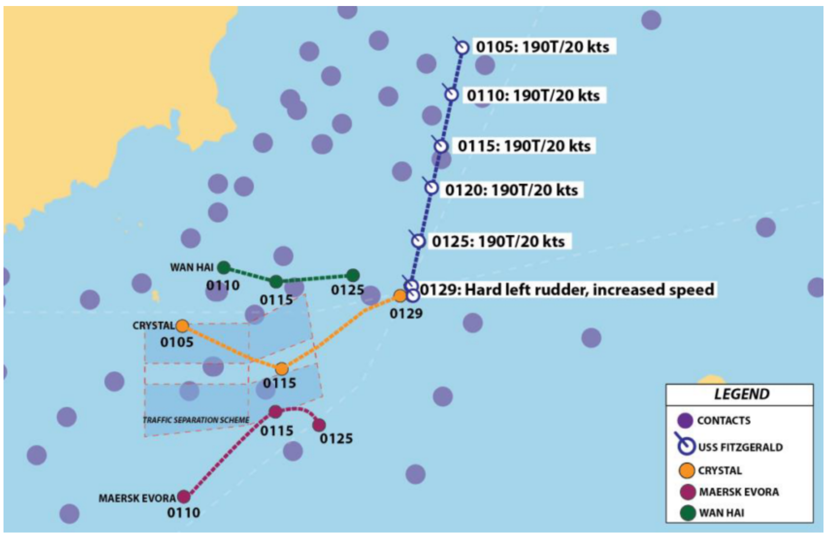

Figure 1.3: Illutstration map of approximate collision location

In accordance with international rules the USS FITZGERALD was obligated to manoeuvrer to remain clear from the other crossing ships. The officer of the deck responsible for navigation and other crew discussed whether to take action but choose not to, till it was too late. While other crew members also failed to provide more situational awareness and input to the officer of the deck. Did the officer of the deck, exhibit poor seamanship by failing to manoeuvrer as required, failing to sound the danger signal and failing to attempt to contact CRYSTAL on Bridge to Bridge radio. In addition, the Officer of the Deck did not call the Commanding Officer as appropriate and prescribed by Navy procedures to allow him to exercise more senior oversight and judgment of the situation. This was prescribed to an unsatisfactory level of knowledge of the international rulles 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 seperation 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. [of the 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 operatoin of the USS JOHN S MCCAIN's steering and propulsion system, while in the presence of a high desnity 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.

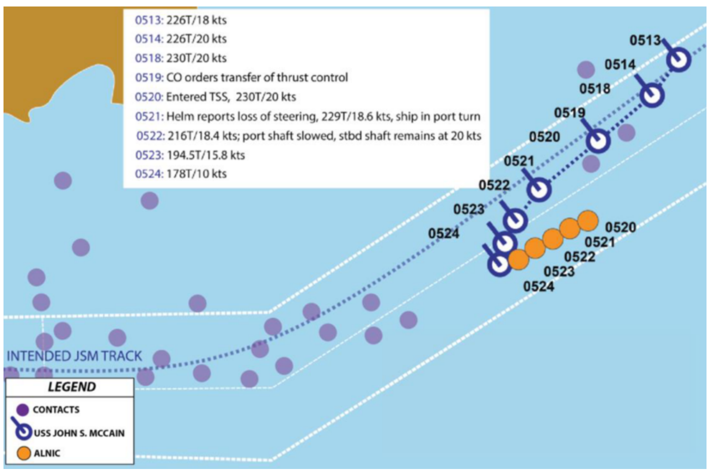

Figure 1.4: Illutstration map of approximate collision location

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 in the watch team, which led to wrong transfers of control, where 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 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 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 trough the VHF bridge-to-bridge communication. Many of the decisions made that led to the accident were the result of poor judgemenet 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. [of the Navy, 2017]

2 | Future of shipping

The shipping industry is traditionally driven by regulations. Digitalization and de-carbonization are watch words for the coming decade. Those will be leading so the shipping industry can become safer, more efficient and at the same time reduce 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 visualise data. This enables ships to continuously communicate with managers and traffic controllers. At first this can be used to analyse data and give better advice based on expected weather, fuel consumption and arrivals at bottlenecks like ports and bridges. Later on this can results 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.

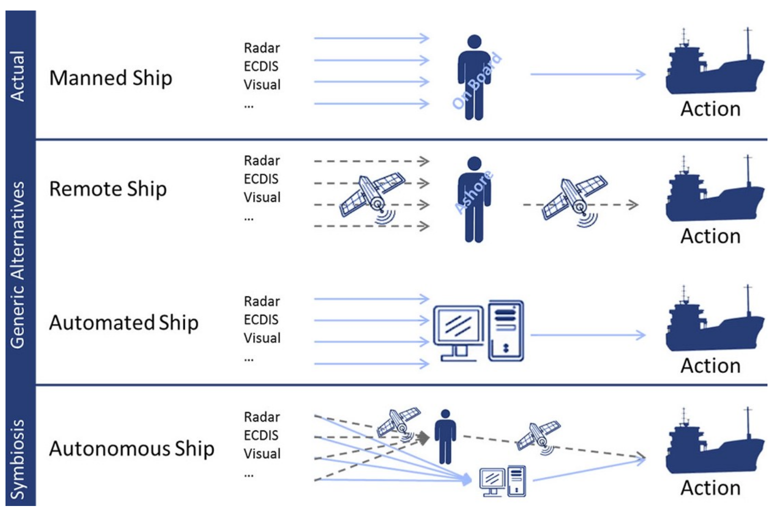

Figure 2.1: From manned to autonomous ships

The research project MUNIN consists of a constortium of shipbuilders and scientists. The name is an abbreviation for Maritime Unmanned Navigation trough Intelligence in Networks. They did an initial research. Focussing on different elements of an autonomous concept: The development of an IT architecture. Analyse tasks preformed on today's bridge and how this will be on an autonomous bridge. Examine the tasks in relation with a vessel's technical system and develop a concept for autonomous operation of the engine room. Define the processes in a shore side operation centre 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. An 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 centre of remote operations. Using an interactive environment with screen for decision support and improving situation awareness with augmented reality. With these developments does their vision look very promising. However it 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 optimisation of waterway maintenance. A good example 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 a group which 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 behaviour 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 preformed around human behaviour, there is thus an opportunity to keep improving the way people are involved. And there capabilities are utilized while mitigating there vulnerabilities.

In short key-words discussed in this chapter

3.1 Situation awareness

Experience is key to improve the skill to scan for hazards. This is known as the situation awareness [Underwood et al., 2013]. Hereby is important to notice that situation awareness is not limited to perceiving, but has multiple levels. This is known as 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 an 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.

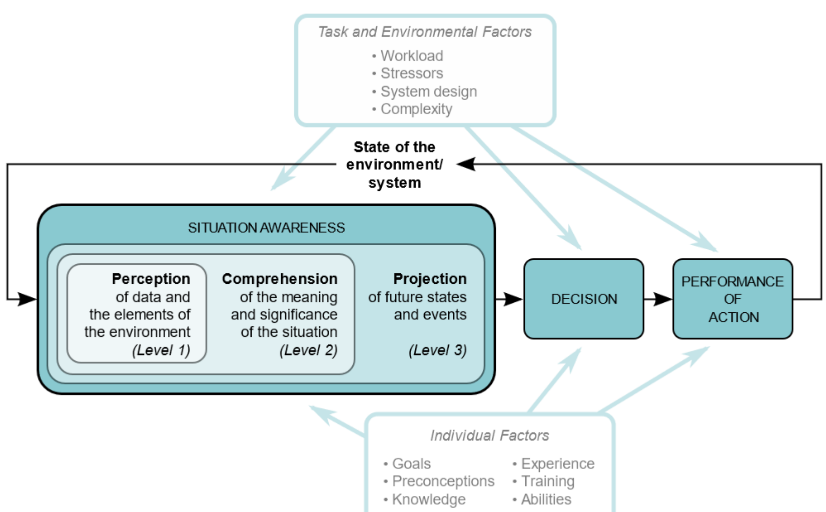

Figure 3.1: Endsley model for Situation awareness

3.2 Mental model

To explain why someone predicts a future state that will occur, it is important to get insight in 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 Sandhaland, based on accidents at the north sea caused by: inadequate design, planning failure, communications failure, distracting elements and insufficient training. The consequences have been 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 around acquiring experience in specific situations. The decision process during 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 have 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 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. [**?**]

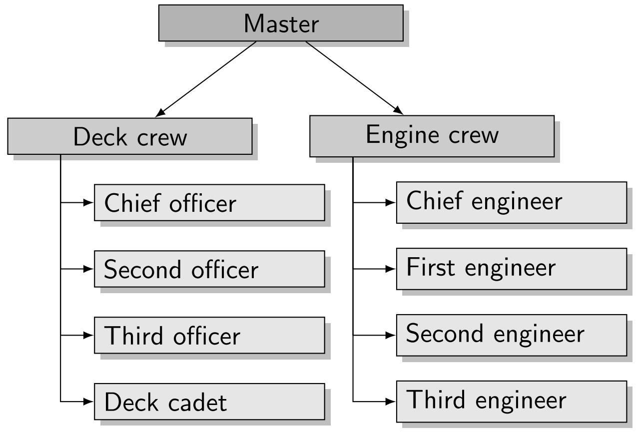

Figure 3.2: Crew structure basic

3.3.1 Deck crew

The Deck crew is in charge with the vessel navigation, watch keeping, maintaining the ship's hull, cargo, gear and accommodation, taking care of the ship's life saving and firefighting appliances. The deck department is also the one in charge with 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 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 with 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 watch keeping, 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 with ensuring the good functioning of the fire-fighting equipment and life saving appliances. He undertakes bridge watches and learns how to become a Second Officer.

A Cadet on board a merchant 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 unmooring the vessel, deck maintenance and cleaning. The AB also secures and unsecures 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 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 with 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. [?]

3.3.2 Engine crew

The engine crew is responsible with operating, maintaining and repairing, when required, 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 in 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 Forth Engineer and it is an operational level job. The Third Engineer is usually responsible with 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 with 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 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 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. [?]

3.4 Possible improvements

Add part on type of change, related to course on behavioural change, including difference between stressfull and normal situations

Does more automation lead to skill degredation in emergency situations? Aviation industry

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].

What will be discussed in this chapter

4.1 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]

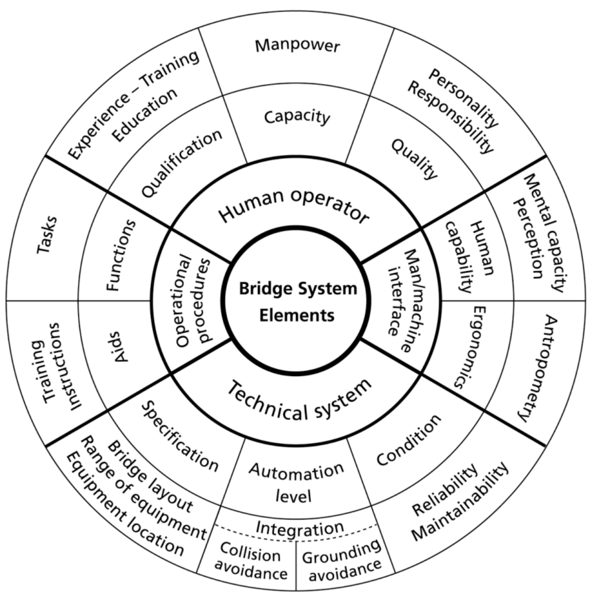

Figure 4.1: Bridge system elements according to DNV GL

4.2 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 presentaiton 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 UIDs and emergency stop for thrusters. Which give information on the thrust, pitch and when provided a conning information display. [DNV GL, 2017]

Add pictures of bridge and different dashboards on screen, separated for different vessels sizes

4.3 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.

4.4 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.

4.4.1 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]

4.4.2 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]

add more research on bridge design (Myrthe Lamme)

4.4.3 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]

add information on JIP which Robert presented, inlcuding the flowchart, if my project is able to use the same philosophy

Many of the Damen vessels are making the step towards integrated bridge systems, which is the next step in a more user centered design. In the future they will also start using more integrated systems, such as Praxis' Mega-Guard IBS or Alphatron's AlphaBridge. Both modular bridge systems use in-house developed instruments. Combining the functionality of Radar, ECDIS, conning, alarms, other ship systems and AIS. Other major players in the development of integrated bridge designs are Sperry Marine with the VisionMaster FT, Raytheon Anschütz Synapsis NX and for yachts Admarel.

Many regulations exist, limiting the freedom for companies to make designs.

Which regulations are leading, IEC code

4.5 Manoeuvring display

The CASCADe project already showed the advantages of an adaptive bridge system. Key in most of these systems is a modification to the overlay in the ECDIS system. This is also chosen as starting point for bridge modifications in this project. As it is already possible using the ECDIS system to add alarms and layers. The developed model will be a white box approach, this will help to define alarms and mark forbidden zones. Thereby need to be taken into account, the rules and regulations for the ECDIS system as defined by the international hydrographic organization.

How is a map build, S-57, .BSB; how to import and modify, preferably with python

4.6 Bridge users

Write down thought process of crew, using one or more known mental model methodologies and in a user story form

The user stories already exist, ask Toine and Robert for them, and most likely also Mark

In those user stories should ALL communication be described. Ask port autorities and pilots which information they want to receive

Add pictures of ECDIS display

Thereby must information overlead being taken into account. The reason not too add another screen is to avoid information overload. While Sandhaland already mentioned how information overload is one of the main reasons for loss of situation awareness. As in most failure cases the right information was somewhere on the screens. But was not perceived correctly by the crew.

Make short user stories for the captain and other crew. Also based on the mental model and thought process of the crew. Which tools do they use in that case.

5 | Model

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, accelation 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?

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 te 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 trough 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 trough, 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 trough 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:

- BIBBY WAVEMASTER 1, off supply vessel with walk-to-work capabilities.
- Damen ASD Tug 2810, standard vessel
- KRISO Very Large Crude Carrier 2, academic standard model

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 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 standard situations might also be based on previous accidents.

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