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MSc Thesis - Current Knowledge
**Model for the complexity of maritime
operations**

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Abbreviations

AIS Automatic Identification System

AMS Alarm Management System

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

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 give a summary of current knowledge and papers which will support my research to: The complexity of maritime situations and how this can be communicated to the crew. As described in the Dutch National Research Agenda an fundamental question we have to ask ourselves: How do we get grip on unpredictability of complex networks and chaotic systems? This research will have two main tracks. The first part is for the department of Maritime Technology and Transport. Where I will try to specify a scale for the complexity where a ship can be in, leading up to an probability value for failure. The second part of the research will be for the Interactive Intelligence department. Where will be looked at the interaction between computers and people. In this case more specific, which information does the crew currently get and what information do they need. So they can improve their situation awareness and make better decisions.

Extend purpose of research with TKI NML

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 an 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

Occurred accidents

Why would we change the current situation? Investigation reports

List some accidents and how these won't occur with different systems

1 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 [1].

Describe in short what will be discussed in future of shipping section

1.1 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 result in unmanned vessels. Either remotely operated from shore, on autopilot or completely autonomous, as shown in figure 1. The different projects around the world follow this same path. Below some of these projects are mentioned with their current status.

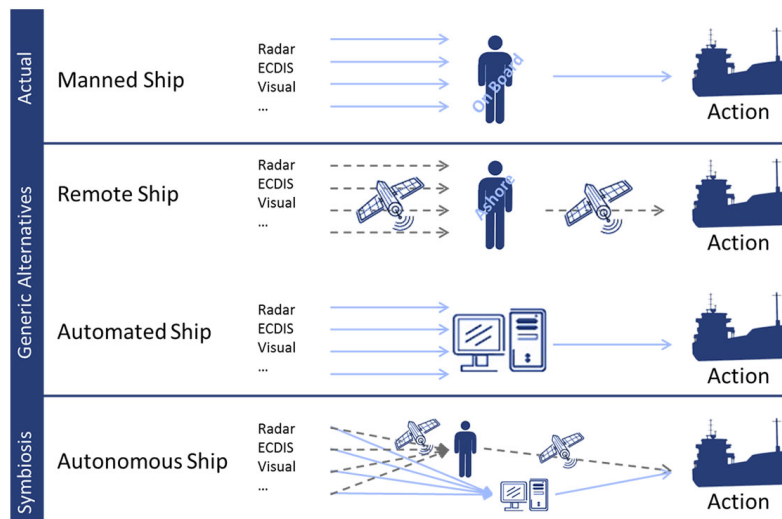


Figure 1: From manned to autonomous ships

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 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 [1].

1.2 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 [2]. 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 [3].

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 optimising the speed, based on opening times for bridges and availability of the quay [4].

Praat met
Boudewijn
Baan - Sales
Manager -
involved va-
nuit Damen
bij Gouwe-
naar

2 Knowledge of the crew

Seafarers are a group which are protected by international maritime treaties: International Convention for the Safety of Life at Sea (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 [1]. Fortunately a lot of research is performed around human behaviour, there is thus an opportunity to keep improving the way people are involved. And their capabilities are utilized while mitigating their vulnerabilities. The ships' crew is leading in this research. Therefore is looked at education they receive and how their knowledge developed. As this determines how they interpret a situation. Regardless of the entry level, every seafarer has to gain years of experience to earn the job title of ship captain, beside several licences and certificates.

extend which
licenses and
the amount
of experience
needed

Experience helps to improve situation awareness, as the skill to scan for hazards is more developed [1]. 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 2), the three levels are [1]:

- **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.

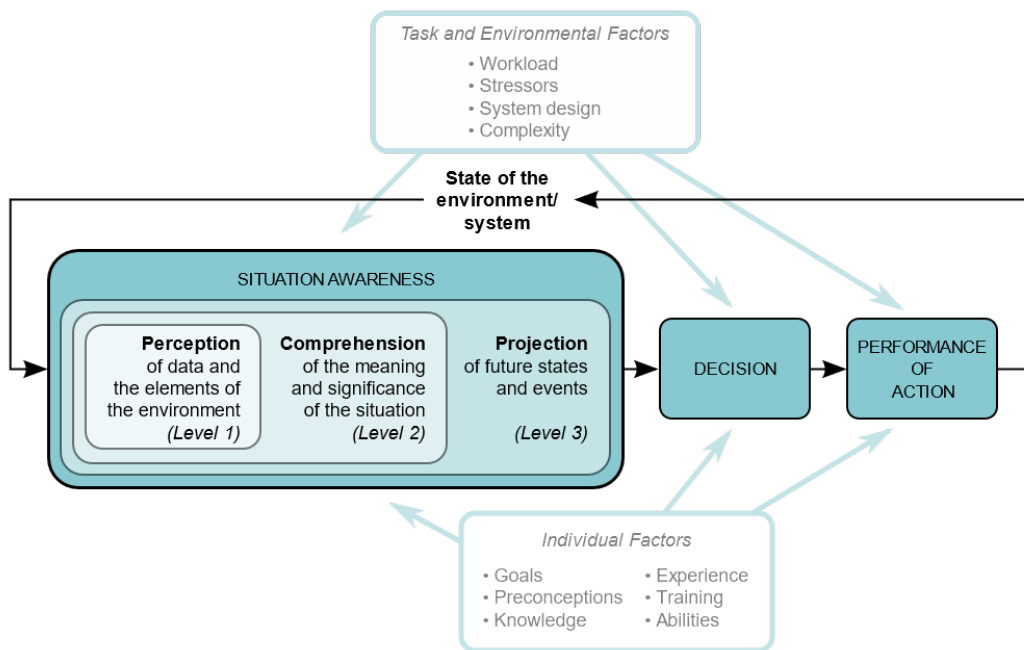


Figure 2: Endsley model for Situation awareness

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 []. 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. [].

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 [] [].

2.1 Situation Awareness

2.2 Decision making and behaviour

2.2.1 Normal situation

2.2.2 Under stress

2.3 Mental models

2.3.1 Theories

2.3.2 Questions by crew

Check if I mention everything, and write down tough process of crew based

3 The bridge

In section 2 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 a 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 [].

3.1 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 3 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. []

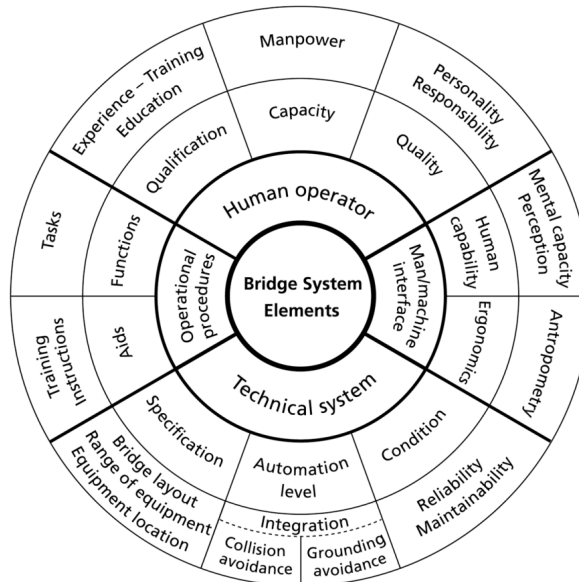


Figure 3: Bridge system elements according to DNV GL

3.2 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, Very High Frequency radio (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, gyro compass selector switch and steering gear pumps.

These different systems have indicators with information on: propeller revolution, speed, 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 UIDs and emergency stop for thrusters. Which give information on the thrust, pitch and when provided a conning information display. []

3.3 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 wheel house, 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.

add years for steam, steel, technological developments

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 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 analogue instrument. Nowadays these are often displayed together at the conning display, while having the separate instruments at less convenient places.

3.4 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. Is a new revolution coming for bridge design using among others: sensor fusion, new ways of visualization and decision support.

Parallel to the research to autonomous vessels, are there many concept for future bridge designs. Both can be traced back to the changes in philosophy on human-computer interaction. Below some of the concepts are explained. Where is mostly is a combination of classification societies, research institutes and commercial companies.

3.4.1 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 on 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 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. [] []

3.4.2 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). []

3.4.3 Suppliers

But currently bridges are already build and the companies developing these are also not standing still. But present more realistic there 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, 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. [] Many of the Damen vessels sail with the Dutch integrated bridge systems, which is the first step towards are more user centred design. Examples are Praxis' Mega-Guard IBS or Alphasatron's AlphaBridge. Both modular bridge system use in-house developed instruments. Combining 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.

add information on cognitive seafarer model

add more researches on bridge design (Myrthe Lamme)

Check systems Damen is using

3.5 Manoeuvring display

The CASCADE project already showed the advantages of an adaptive bridge system. Key in most of these systems is an 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 organisation.

3.6 Information overload

The reason not too add another screen is to avoid information overload. While

- Kongsberg Maritime - Alewijnse - Praxis

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

As mentioned in previous chapter does the crew make decisions based on situation awareness, created by the information given. This information they do receive at the bridge.

From rules is given an bridge is equiped with screen, sensors, etc.

This has been so far mostly an evolution, with putting more equipment up. Leading to a possible information overload.

There are projects at allewijnse/alphatron/praxis/Damen? who work on new bridge designs. This is the user interface of the ship.

Looking at design choices which can be made for an user interface you can find amount of screens, buttons/touch, offshore the demands are different. Thus should be changed.

This is higly related to information overload and decision making under stress

3.7 Bridge design

3.8 User interface

3.9 Processable information

In the cases where the crew was not able to monitor properly, often the right information was somewhere on the displays. But as that

4 Model

4.1 Physical models

4.1.1 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.

4.1.2 Environmental forces

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

4.2 Route planning

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

4.3 Cost function

4.4 Monitoring

4.4.1 Environment

4.4.2 Ship

Conclusion

Wrap-up

write the
scope of the
project

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