MASTER THESIS

THE DEVELOPMENT OF AN IDENTIFIABLE, INTEGRATED, AND USER FOCUSED SHIP BRIDGE CONCEPT FOR DAMEN SHIPYARDS

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“The best way to predict the future is to create the future”
- Rolls-Royce

ABSTRACT

The research is performed for Damen Shipyards, a Dutch shipbuilding company, and is about the main control position of a vessel: the bridge. Due to technology evolvement and regulatory demands the ship bridge has become a cluttered work environment. To reduce the risk of human errors in operations, their work environment needs to be improved. The overall objective is to develop an identifiable, integrated, and user focused ship bridge concept which should lead to more efficient and safer operations.

First the bridge environment, functions, operational demands, human factors, and technologies are analyzed. User observations during operations reveal several usability issues on the bridge, in the field of ergonomics, human-machine interaction, and appearance. Their origin can be traced back to three main root causes: (1) a lack of knowledge within Damen about human factors and operational demands, (2) business processes, like less knowledge sharing between different departments, and (3) a low level of user involvement during the design process.
Considering the trend that the maritime industry will move towards smart vessels with more automated functions, attention has to be paid to user interface design and cognitive ergonomics. This leads to the overall research aim to: ‘Compose an integrated design philosophy to decrease the system complexity and increase the interfacing performance’.
To be able to improve the current bridge and its environment as an integrated whole, the underlying development process is streamlined as outlined by a design strategy. This strategy also pays attention to the root causes of the usability issues, and ways to tackle them. A strategy roadmap is provided to support the implementation of the strategy and its key values. By performing a case study with an Azimuth Stern Drive tug, insight is created in the application of the strategy, its processes, and the related design philosophy. Hereby a wheelhouse alarm, monitoring, and control system concept is developed that has to support the operator to look outside and to maintain its situational awareness. The system concept is tested with users whereafter a design iteration is performed.

To come to a complete and integrated wheelhouse concept also other aspects that influence the user experience and vessel operation have to be taken into account. So the concept need to be developed further and tests have to be performed in the field. However the strategy and concept already serve as an important step in enlarging the operational performance and safety.

GLOSSARY OF TERMS

ABS	American Bureau of Shipping; an American classification society
Bridge	The area where the navigation, maneuvering, and control of the vessel takes place
Classification society	An independent, self-regulating auditing body that provides classification and statutory services in order to support overall maritime safety. A vessel that is designed and built according to the rules of a society may receive a certificate of classification from that society (International Associations of Classification Societies [IACS], 2011)
Console	A panel which contains the main bridge equipment and input controls
Course	The direction through water in which a vessel is intended to sail, defined as an angular distance from the North. This may not be the actual direction since current and wind can influence this
DNV GL	Det Norske Veritas and Germanischer Lloyd; a Norwegian classification society
Heading	The real direction a vessel sails (defined as an angular distance from the North) in order to compensate for weather influences like wind, current etc.
IMO	International Maritime Organization
Lloyd's Register	An English classification society
Maneuvering	The control of a vessels' position and heading; the movements of a vessel on the short-term (Petersen & Nielsen, 2001).
Mental model	The user's expectations when interacting with products, formed by experience, training, and instruction (Wickens, Lee, Liu & Gordon Becker, 2004)
Mimic	A visual representation of information which is shown on a display device
Navigation	A vessels' voyage planning on the long-term (Petersen & Nielsen, 2001)
Route	A path from location A to location B
Track	The actual path of a vessel through water. Herein the weather influences like current are taken into account.
Pilot	An experienced sailor who has to maneuver large vessels through congested waters like a harbor
Pilot vessel	A vessel that is assisted by a tugboat
Wheelhouse	The total construction on top of a vessel in which the bridge is located
Workstation	A position where a task or a set of related tasks can be performed (Lloyd's Register, 2016)

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INTRODUCTION

This is my final thesis for graduating the master of Industrial Design Engineering at the University of Twente. This graduation has been performed at the Damen Shipyards Group located in Gorinchem, the Netherlands. Within Damen
I will be graduating at the department of Engineering Tugs. My research is about a ship's navigational bridge, with the aim to explore new, user friendly solutions and to develop an integrated Damen ship bridge concept by investigating human factors, operational demands, and technologies.

The research is outlined in two parts: (1) this Thesis and (2) a Research synthesis. The Thesis describes the approach of the research, the processes that are performed to come to an integrated ship bridge concept, and the rationale behind decisions that are taken. The Research synthesis gives overview about the application of the most important research findings, the end result, and tools that can support Damen in bridge development.

In this section first the Damen Shipyards Group is introduced, followed by an introduction about the research topic and the research approach.

Damen Shipyards Group

The Damen Shipyards Group is a Dutch family owned shipbuilding company founded in 1927. Damen designs, builds, and services ships for all kind of markets and purposes like offshore oil and gas, yachting, public transport, and defense and security. The company operates globally in (niche) markets and therefore owns a lot of specialized yards worldwide; 32 yards in total. This makes it possible to build their vessels close to any delivery destination.
Damen's shipbuilding concept, 'The Damen Standard', is a combination of standardization and customization. This means that the hulls of their ships are standardized for each (niche) market. By having these hulls on stock, delivery times can be reduced and lower costs can be achieved (Damen Shipyards Group, 2015).

The Damen Shipyards Group consists of three main divisions:

- Damen Shipyards Gorinchem: headquarters
- Royal Schelde: naval division
- Amels: yachting division

In addition it manages a lot of small companies like Damen Marine services.

Damen Shipyards Gorinchem consist of four business units and their related Product Groups, see table 1.

Business units	**Includes the Product Groups**
Workboats	Tugs, Workboats, Dredging
High Speed Craft (HSC)	High speed craft vessels, Fast ferries
Cruise & Offshore (C&O)	Offshore & Transport, Cargo vessels, Yacht support/ SeaXplorer, Cruise & Ferries
Damen Technical Cooperation (DTC)	All Product Groups

Table 1: Business units Damen Shipyards Gorinchem

Damen Technical Cooperation provides a prefabricated shipbuilding kit to build everywhere on-site. Also expert assistance and training can be part of this package (Damen Shipyards Group, 2015).
All business units consist of the same departments like Sales, Design and Proposal, and Engineering.
The main stakeholders that are involved by building a Damen ship are shown in figure 1. Note that the customer is not always the actual user.

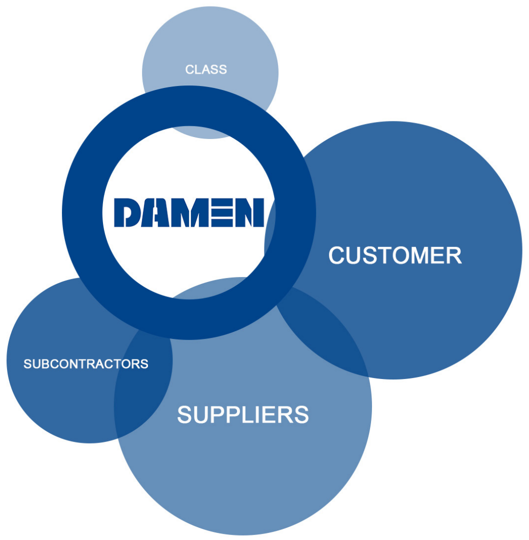

Figure 1: Stakeholder map

Research

Problem statement

Due to technology evolvement and regulatory demands the amount of equipment components on a ship bridge has increased. This has led to a cluttered work environment with a lot of separate components that all require their own means of interaction. This does not contribute to an efficient use of several functions and thus efficient operations. Moreover it hinders the operator from keeping its eyes on the outside environment and decreases its situational awareness. It can be concluded that a better integration of ship interfaces is necessary to improve interaction between bridge equipment and its user(s), in order to contribute to more efficient and safe operations.

The long term strategic goals of Damen are to increase the quality of their products, to bring their cost price down, and to shorten their lead time. In order to compete against their competitors Damen has to stand out, especially in this challenging period of time. One opportunity to differentiate themselves from their competition is by providing a ship bridge that supports the user in an optimal way. To achieve such a bridge the underlying development process of this part of the vessel has to be streamlined first. By improving the development process, the quality of the related end product will increase as well. So by applying a clear development strategy, this will contribute to the achievement of Damen's long term goals in the end.
The overall objective of the research is stated as 'The development of an identifiable, integrated, and user focused ship bridge concept for Damen Shipyards'.

Research approach

The research can be divided over the three main phases: Foundation, Specification and Design, and Evaluation. These phases comprise several activities, which are shown in the overview of figure 2.
To gain insight into the research subject and its context, the stakeholders, Damen vessels, bridge environment, bridge systems, and related regulations are analyzed. A literature study is applied to gather knowledge about the human element on the bridge, to indicate the relevance of the research, and to provide a scientific foundation for the research. Also the Damen business processes are analyzed to ensure that the design strategy will match the organization and their way of working.
To achieve a ship bridge concept that works in an effective, efficient, and satisfactory way, knowledge about user goals, interaction (principles), and user needs is determined and the actual use is observed.
Functions, tasks, routines, and experiences of the bridge crew are brought into play to ensure that the concept and its components support the user during operation. The objective is to optimize the bridge environment around how users can, want, or need to use the system, rather than forcing them to change their behavior to accommodate the environment and its systems.
To explore future possibilities and opportunities and to be able to respond to future changes, information about new technologies and trends is included. The Foundation phase will conclude with the determination of the research scope; the focus area for the further research. This will be done on basis of the insights acquired during the studies.

During the Specification & Design phase a case study will be performed to validate the decisions and the results that are made and acquired so far. Hereby a concept is developed which will be tested with actual users. An iteration of this concept will lead to the final concept.
The total process and end result are evaluated in the Evaluation phase, whereby recommendations are given.

Note that the sequence of these steps is not incremental since an iterative design approach is pursued.

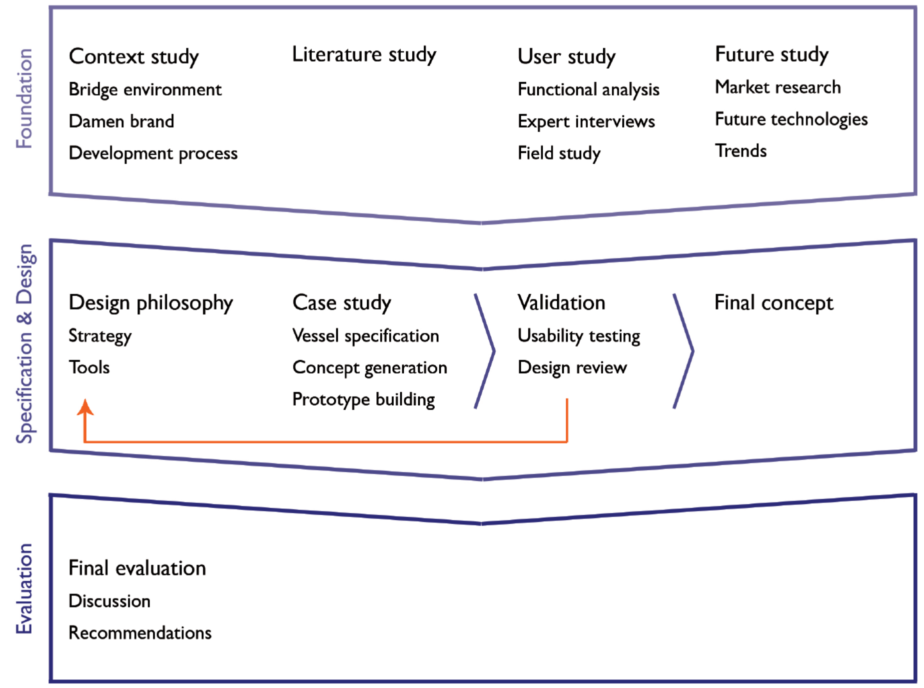

Figure 2: Research approach

PHASE I
FOUNDATION

The aim of the Foundation phase is to gain insight into a variety of subjects which can be used to provide a bigger picture about the maritime industry, the bridge environment, and the related stakeholders. It will clarify the possibilities, opportunities, challenges, and constraints in bridge design, which will be used to determine the research scope. It also gives insight in the dependencies between different elements of the bridge environment.
The Foundation consists of four main parts: a context study, literature study, user study, and future study, which are outlined respectively. These studies form the basis for the course of the research and provide input for the actual design.

1. CONTEXT STUDY

During the context study the context of a general ship bridge is analyzed. First the ship bridge environment, its technical systems, and the rules and regulations that apply to this environment are outlined. This is done in order to gain a general understanding about the environment and to determine the elements that are of importance within this environment. Since the aim is to develop an identifiable Damen concept, a Damen brand analysis is performed. This provides insight in the key values of the company which can be taken into account during the development of the concept later on.

The underlying development process of the bridge determines to a great extent the bridge design. So therefore the current Damen bridge development process is analyzed. This will provide insight in how these processes influence the bridge design, and possibly where these processes can be improved. These insights will also help to ensure that further development of the concept matches the corporate proces- ses and procedures within Damen.

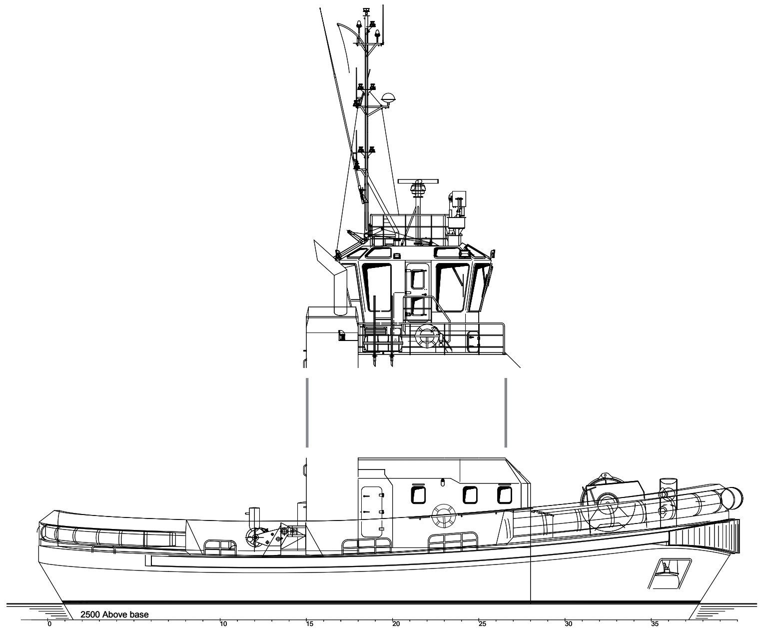

Figure 3: Wheelhouse (top) and ship (bottom) (ASD tug 2310 side view)

1.1 Ship bridge

The ship bridge is the main control position of a vessel and is located inside the wheelhouse. The wheelhouse refers to the entire outer structure of the top compartment of the vessel, see figure 3. The bridge refers to the equipment and components that are positioned within the wheelhouse and that allow for operation of the vessel, see figure 4. The wheelhouse and bridge are

Figure 4: Inside a wheelhouse: bridge consoles and components

positioned on top of the vessel to allow for optimal sight and observation of the outside environment and surrounding vessels (Wahlström, Karvonen, Kaasinen, & Mannonen, 2016).
The ship bridge is functionally interrelated to the engine room, which is located below the main deck. The engine room contains among others the main propulsion engines. The bridge can be seen as the vessels' 'brain' since the decision making is performed here, and the engine room can be seen as its 'heart' since the propulsion is located there (van Dokkum, 2011).

According to the regulations of the International Convention for the Safety of Life at Sea [SOLAS] (2007) the ultimate purpose of a ship's bridge is to ensure safe operation of the ship. The bridge should be designed to assist in:

- facilitating the tasks to be performed by the bridge team and the pilot in making full appraisal of the situation and in navigating the ship safely under all operational conditions;
- promoting effective and safe bridge resource management;
- enabling the bridge team and the pilot to have convenient and continuous access to essential information which is presented in a clear and unambiguous manner, using standardized symbols and coding systems for controls and displays;
- indicating the operational status of automated functions and integrated components, systems and/or sub-systems;
- allowing for expeditious, continuous and effective information processing and decision-making by the bridge team and the pilot;
- preventing or minimizing excessive or unnecessary work and any conditions or distractions on the bridge which may cause fatigue or interfere with the vigilance of the bridge team and the pilot; and
- minimizing the risk of human error and detecting such error if it occurs, through monitoring and alarm systems, in time for the bridge team and the pilot to take appropriate action. (SOLAS, 2017, p. 1)

1.2 The total bridge system

According to Det Norske Veritas (2011) the total bridge system consists of four parts:

1. The human operator; evaluates information and takes decisions
2. Operational procedures; to make sure that the total bridge system performs best in different situations
3. The technical system; provides information and is used for the handling of the ship
4. The human-machine interface; provides interaction between the system components and the operator

All parts should be in alignment in order to function as effective, efficient, and satisfactory as possible (Det Norske Veritas, 2011). The aspects are further elaborated below in order to provide more insight into their context within the bridge environment.

1.2.1 Human operator

The number of crew members that are working on a ship differs per vessel type, however the main positions that have to be managed by the bridge crew are:

- Captain; controls the ship
- Helmsman; takes care of the radar and is lookout, also controls the ship when the captain is absent
- Navigator; takes care of the navigation
- Chief engineer; performs maintenance and ensures the functioning of the technical systems

On smaller vessels some positions are combined like the functions of captain, helmsman, and navigator.

The captain is the primary user of the bridge. The general characteristics of a captain are given below.

Gender:	Male
Age:	20-65 years
Nationality:	Nationalities from the continents Africa, America, Asia, Europe, and Oceania
Educational background:	Naval school, secondary vocational education ('MBO') / higher professional education ('HBO')
Knowledge:	Ship handling, navigation, mechanical engineering
Characteristics:	Pragmatic, straightforward, hardworking

1.2.2 Operational procedures

The bridge environment has to accommodate and support the following main functions (Lloyd's Register, 2016):

- Navigation and maneuvering
- Monitoring
- Manual steering
- Docking; performing (un)berthing operations
- Planning
- Safety
- Communication
- Conning; controlling the vessels' course

In the functional analysis of section 3.1 the interrelations between these functions will be outlined.

1.2.3 Technical system

Figure 5 provides overview of a conventional bridge arrangement with the positioning of the different functional areas.
Different systems are provided to monitor and control the navigation and the position of the vessel and its surrounding vessels. Several input devices are provided to operate the vessel itself (Olsson & Jansson, 2006).

Since the navigation, maneuvering, monitoring, and manual steering tasks are interrelated, their input devices are usually placed close to each other (American Bureau of Shipping [ABS], 2003).

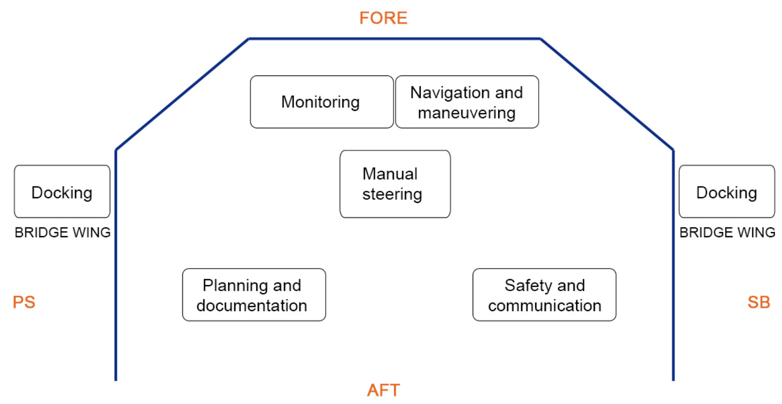

Figure 5: Conventional bridge arrangement of functional areas (International Maritime Organization [IMO], 2000)

Automation system

The general architecture of a ship's automation system is outlined in figure 6.
The operator stations and control panels show the system state and enable the operator to monitor and control (parts of) the system. Cabinets receive system and sensor information (input/output) and process this data.

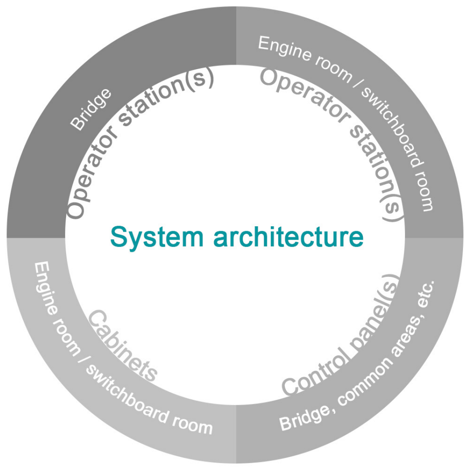

Figure 6: System architecture automation system

1.2.4. Human-machine interface

During operation the operator interacts with different systems and components on the bridge to perform its tasks, whereof the most important ones are outlined in Appendix A: Bridge systems. An interface is part of a system and can both receive input from the user as well as show output to the user (Opperman, 1994).

The last decade's the technology development process has evolved at a rapid rate. This has led to an increase of advanced automation systems and thus a more complex bridge interface, which brings along some concerns (Grootjen, Bierman, & Neerincx, 2006):

1. Increasing cognitive load and fluctuations in information volume
2. Increasing task integration of different tasks on the bridge; this requires more flexibility of the operator and the system
3. Increasing system autonomy; this leads to a shift in the role of the operator from monitoring and control towards supervision
4. Increasing system complexity; this leads to more complex problems
5. Decreasing personnel and training budgets; this asks for intuitive systems
6. Increasing legislative system constraints

The readability of indicators, visual display and input devices in relation to the operator's line of sight is shown in figure 7. Different priority zones can be distinguished: immediately readable, easily readable, and available. Information that has to be immediately readable should be located within a 60° overhead view from the operating position and within a 180° overhead view if it has to be easily readable. From a sideward view it has to be an 80° view for immediate readability and a 150° view for easy readability (Det Norske Veritas and Germanischer Lloyd [DNV GL], 2017).

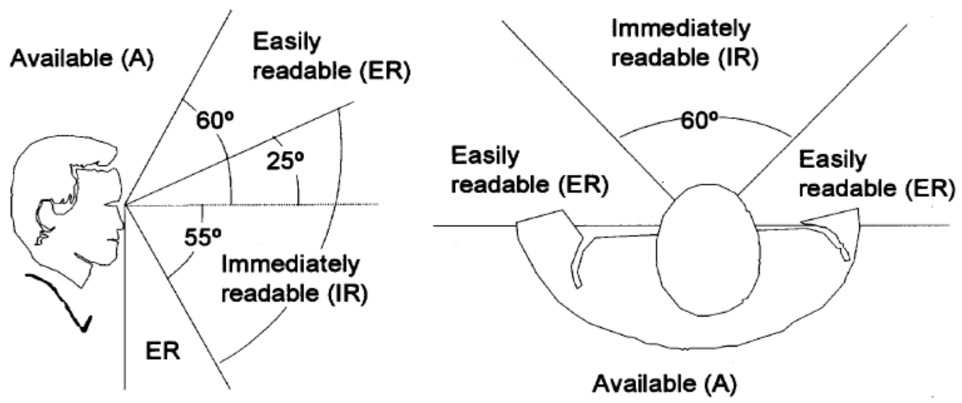

Figure 7: Different areas of readability from forward view (DNV GL, 2017)

Different reachability zones for input devices from standing and seated position can be found in Appendix B: Reach envelope.

1.3 Rules and regulations

To ensure safe operations and international consistency a lot of rules and regulations apply for ships, which are defined by different Classification societies. An overview is given of the most important requirements for the bridge environment in Appendix C: Rules and regulations Classification. Regulations about the ergonomics of the bridge environment are available but are often formulated on a basic level. For example those regarding the operator interface: "Integrated display and control functions are to adopt a consistent man-machine interface philosophy and strategy. Particular consideration is to be paid to symbols, colors, controls, and information priorities". Or, "Keyboards are to be divided logically into areas enabling rapid access to a desired function. . ." (Lloyd's Register, 2016, p. 1551). So to support Damen in developing integrated ship bridges that support the user in an optimal way, more specific design principles and requirements have to be drafted in the field of bridge design, instrument arrangements, ergonomics, and information presentation.

1.4 Damen brand analysis

The objective is to develop an identifiable and recognizable Damen ship bridge concept. But what makes Damen actually recognizable according to their brand and their vessels? To find out a basic Damen brand analysis is performed. Furthermore the Damen style characteristics are analyzed.

The 'Brand identity prism' of Kapferer (2008) is used to provide insight in the strengths and opportunities of Damen as a brand, see figure 8. This prism shows six dimensions of brand identity, with the Damen values included.

'Physique' covers the physical features that is thought of when the brand name is mentioned. 'Personality' refers to the brands character. Relationship' alludes to a certain relationship the brand has to symbolize between people. 'Culture' includes the organization values. 'Self-image' shows how the target group sees itself, and 'Reflection' describes the typical consumer as perceived by others (Kapferer 2008).

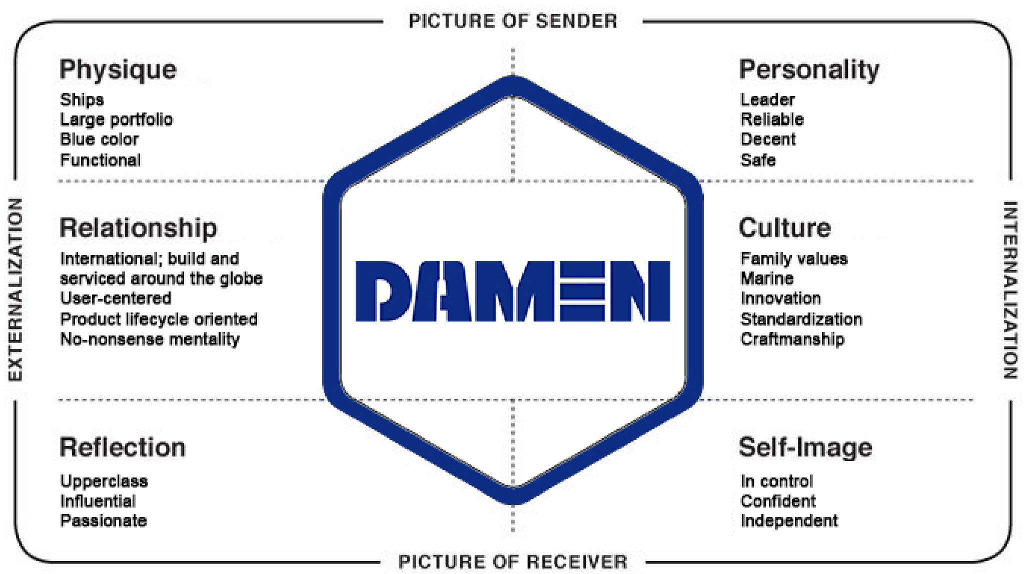

Figure 8: Brand identity prism Damen Shipyards

The related strengths and opportunities are summarized below.

Strengths
- Configuration of ships
- Providing a complete solution: designing, building, servicing, repair- and converting ships, and delivering components
- Short lead time of their vessels
- Active in all kind of (niche) markets

Opportunities
- Take more advantage of ergonomic and human factors principles
- Adoption of new ideas and feedback, in this way the position of inventor and frontrunner can be improved
- The use of more standardized components over the different Product Groups
- Build a stronger brand by implementing several style characteristics; build a recognizable family of ships

1.4.1 Damen style characteristics

There are currently less style characteristics that distinguish Damen vessels from their competitors. According to the Design & Proposal department of Tugs, the design of Damen ships is mainly dictated by functionality, hydrodynamics, and efficient production. For example the wheelhouse is designed in such a way that it creates ultimate sight for the operator.
When looking at the bridge, also less style elements are incorporated to give it a Damen identity; only the Damen logo is included in several components. Furthermore, the bridges itself differ completely in their design on different vessel types, which is mainly caused by the application of components of different suppliers. Also a clear overall Damen bridge design philosophy is lacking.
On the one hand it is obvious that different practical applications of the vessels also require different designs, materials, and details. For example tugs do not carry commercial passengers, so functionality prevails over luxury. On the other hand a uniform appearance and more consistency between the vessels can strengthen the ability to recognize the Damen brand, and the associations (potential) customers have with Damen and their products. In the end this can lead to an increased brand and product value, and increased customer satisfaction and profit (Kapferer, 2008).
Moreover, by standardizing certain style characteristics it will be easier to patent them, which contributes to better protection of Damen ship designs in general.

1.5 Damen bridge development

To come to an integrated ship bridge concept it is important to ensure that the underlying development process is performed in an effective and efficient way, since this forms the basis for the related design. The activities performed during development and the way how they are performed determine to a large extent the final product design. And are thus of influence if the product is experienced as successful by its users. Activities that are crucial in developing a successful product are for example integration of different departments to share knowledge, involvement of the user and testing to be able to fit the user and its needs.
To improve the current bridge design the development process is analyzed first. Hereby also areas of improvement within this process are mentioned.

A customer has two options when ordering a Damen vessel: get a standard bridge or get a custom one. Standard means that the customer buys a total system solution, so the bridge design is mainly dictated by Damen. Hereby options are offered to include extra components if preferred.
Custom means that Damen will do a proposal for a bridge that is designed according to specific customer wishes. However, the amount of influence the customer can have differs per product type. In general it applies that small vessels allow for customization on a smaller scale than large vessels.
The current stages of the bridge development process are:

- **Initial design – Design & Proposal**
  The general arrangement and functional specifications are defined, on basis of the type of ship, its purpose, and its dimensions.
- **Design check - Engineering (in collaboration with the relevant project managers)**
  The information that origins from the initial design is audited. It is especially of interest for one-off's and first of series to establish good starting conditions for the subsequent engineering process. For standard vessel types the design check is relevant in case of customizations that have a large impact on the design process.
- **Basic engineering – Engineering and Design & Proposal**
  Arrangements, schematics, and a general construction plan are created. During this phase Damen works closely

with its co-makers and suppliers.

- **Detailed engineering – Engineering**
  The general plan is elaborated in detail and the final technical drawings and 3D information are drafted. The objective is to perform detailed engineering as near as possible to the production yard to support knowledge sharing between Engineering and Production. Detailed engineering is executed by engineering partners that are owned by the Damen Shipyards Group such as Damen Shipyards Galati in Romania.
- **Production (support) - Project manager**
  Components are produced and/ or assembled on shipyards, often abroad. In Gorinchem only the 'special' vessels are assembled, like the one-offs or first of series. Production support is provided during construction and outfitting.
  A factory acceptance test (FAT) is performed for customized bridges to check their technical system on its specifications.
- **Installation and testing - Yard**
  Installation of the bridge is performed at the yard where the relevant vessel is build. A harbor acceptance test (HAT) is performed in port, to check if the technical system and its interfaces work as intended. Hereafter Classification checks if the entire vessel is compliant to specific rules and regulations.
  A final sea acceptance test (SAT) is performed to test the operational performance of the ship.

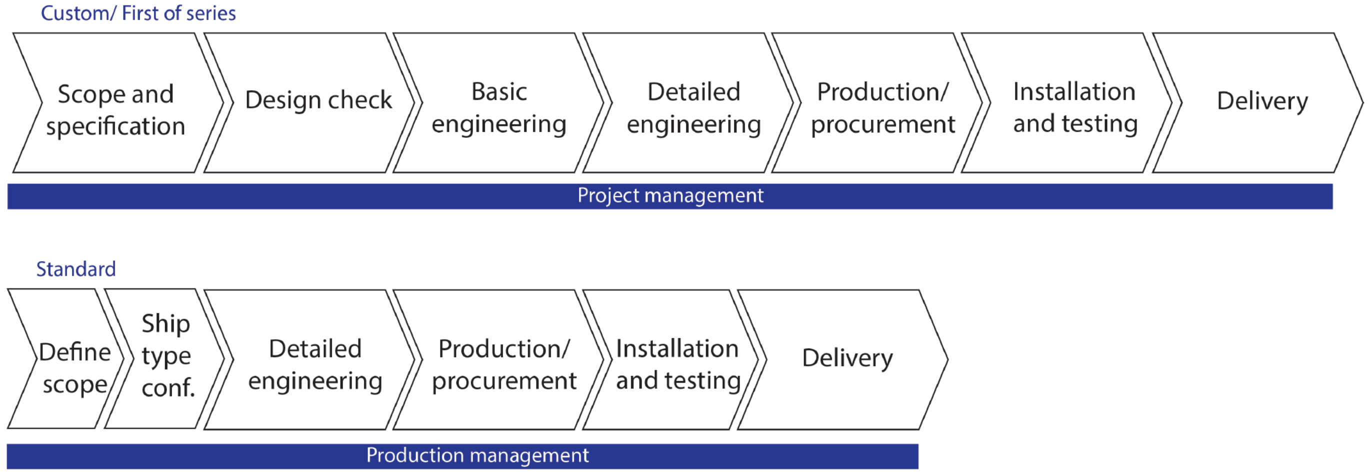

Figure 9: Stages of the Damen bridge development process

The bridge development process of figure 9 is mainly based on the activities that are performed during vessel development, while development of the bridge environment requires a different approach. Since the bridge serves as the work environment of the operator its perspective should also play an important role during development. Moreover development can be approached in a more iterative way, to improve the design already during development and to perform it in a more efficient way. For example by performing iterative testing with the user.
It also became clear that less innovation is performed in bridge design by the Damen Product Groups; the design does hardly change over time and does not respond to technological changes. Currently the main drivers for changing a standard bridge design are:

a) When functions, systems or equipment become obsolete
b) Legislation changes
c) A product update, often driven by client wishes or cost reductions

The frequency of revising this standard differs greatly among the different product categories. Though for all categories it is important to respond to changing operational needs, and new technologies, production techniques, and materials. In order to distinguish from competitors, and to be able to develop a product that fits the user best. By offering products that are really demanded this will help Damen to stand out in the market.

So the development process can be improved by updating and iterating the design on a regular basis, which is mainly driven by operational needs, user needs, and technological innovations.

1.6 Conclusion context analysis

If Damen wants to reach their goal to be considered as an international top brand it will need a clear and more detailed vision on the development of their vessels. Hereby more knowledge is needed about the actual use of their products and the interaction with the actual users.
Currently the bridge is approached as a separate part of the vessel; however it should be seen in the context of the wheelhouse and vessel, in order to allow for complete integration. Therefore the entire wheelhouse has to be taken into account during development.
The Damen development strategy is mostly focused on ship-building but not elaborated to the level of the bridge or wheelhouse. Moreover Damen's key value 'standardization' is not applied to the level of bridge design and to the appearance of their vessels. A wheelhouse design strategy has to be created in order to allow for an efficient design process and to achieve qualitative and consistent wheelhouses. During this design process more attention can be paid to continuous improvement. Integration of (future) users can be valuable to provide input from practice. Moreover implementation of new (innovative) ideas can provide an opportunity for Damen to stand out in bridge design.
To create products with a Damen identity also a clear vision on the appearance and style characteristics of their products is needed. Guidelines have to be created in order to achieve unity and consistency in the exterior and interior design and styling of vessels within the Damen portfolio.

2. LITERATURE STUDY

The user plays a crucial role in ship handling and thus within the wheelhouse. However knowledge about the human element, and especially into the interaction between the operator and the wheelhouse, is currently lacking within Damen. While this knowledge is important in achieving a wheelhouse design that contributes to efficient, safe, and comfortable operations. So more insight in user interaction and aspects that influence human performance is necessary. This will be provided by analyzing the user in practice during the user study. Though first some knowledge about these topics is gathered by means of a literature study. The literature study will summarize the main insights that are already revealed by research in this field. The objective is to provide an overview of the elements that appear to have a significant influence on interaction and human performance. This will provide insight in problems that may arise during operation, and in their causes. It will also make apparent which elements are of importance to support the operator in doing its tasks. Hereby is has to become clear how these aspects can be taken into account during development, in order to achieve a bridge environment that supports the user in an optimal way. Moreover the results of the literature study will provide guidance during the user study.
So a knowledge base is provided that is based on multiple perspectives and studies, which can be used (by making choices) during development.

In this section first the importance of effective and efficient human-machine interaction are outlined, and the role of human factors herein is emphasized. Also several aspects that can influence the human performance are illustrated, whereby is described how this can affect the operators' performance within the wheelhouse.

2.1 Human-machine interaction

The wheelhouse contains a lot of interfaces with which the operator has to interact in order to perform its tasks. To achieve effective and efficient human-machine interaction (HMI) human factor principles have to be taken into account during design. Costa, de Vries, Dahlman & MacKinnon (2015) distinguish three types of human factors:

1. Physical ergonomics; relates to the design of physical objects whereby the human physical abilities are taken into account
2. Cognitive ergonomics; relates to system complexity, human information processing, and the logic between cognitive information and related physical tasks
3. Organizational ergonomics; relates to the efficiency of performing tasks

The current bridge design will be reviewed on these factors, which is done during the user study. In this way it can be assessed in which area improvements might be useful and how the human-machine interaction can be improved. By applying human factor principles in the right way it will contribute to an increasing operator's awareness and productivity, improved operators' comfort, and reduction of human errors (Wickens et al, 2004; Hollnagel, 2003). Furthermore there can be dealt with the concerns as described by Grootjen et al (2006) in paragraph 1.2.4: Human-machine interface.

2.2 Human performance

Figures have indicated that humans are responsible for 70 to 80 percent of the accidents in the maritime industry (Health and Safety Executive, 2003). To determine the causes of these human failures, the human performance is analyzed.
External environmental conditions like movements due to waves, illumination, glare, and reflection can directly affect the human performance during operation at the bridge. However in general it can be stated that the main factors that influence human performance are workload and situational awareness. Both concepts and their impact on human performance are outlined in more detail below. Hereby also the influence of the increasing digitalization is illustrated.

2.2.1 Human workload

The amount of tasks a human has to perform within a certain time span is called workload. How the workload is experienced is dependent from the type of task, task complexity, and the amount of stages that are required to perform a task. Also person specific characteristics like intrinsic motivation, experience, state, and individual capabilities influence workload. This means that the level of workload can be experienced different among individuals for the same task demand (de Waard, 1996).
During operation the operator has to perform a lot of tasks, see also the task analysis in chapter 3. A high workload has a negative influence on the performance of these tasks. So the aim is that the bridge environment supports minimal workload and thus allows for optimal performance. For example by providing a calm and uncluttered work environment and by offering the user more guidance in performing its tasks.

Cognitive task load

Cognitive task load is about the mental effort that is required to perform tasks. The cognitive task load model of Neerincx (2003) describes three aspects that have a significant influence on task performance and mental effort:

1. percentage time occupied; time needed for the interpretation of systems and information provided
2. level of information processing; the amount of information (sources) and the complexity of the information provided
3. task-set switching; the amount of tasks that have to be performed at the same time

The technological evolution and introduction of more complex (automation) systems and interfaces has led to an increasing amount of information sources that have to be monitored. This excess of information makes it more difficult for the operator to quickly process the information and to perform tasks according to its goals (Grootjen et al, 2006). Furthermore, it delays the decision making process which can be crucial in some situations (Endsley, 1995).
It can be concluded that all three aspects as described by Neerincx (2003) are increased over time, which also means that the cognitive task load has increased. In the end this leads to fatigue and problems in human performance.
However in some cases the introduction of automation systems has reduced the operators' workload. For example the Automatic Radar Plotting Aids (ARPA) made it possible to automate calculations and to plot procedures regarding collisions (May, 1999).

2.2.2 Situational awareness

Evaluation of maritime accidents shows that 71% of the incidents is caused by decreased situational awareness (Hetherington, Flin, & Mearns, 2006). Situation awareness relates to situation understanding; what is the current state of the vessel and its environment and how will it react on certain decisions?
The dynamic environment of the bridge requires to quickly understand and react on changing situations (Endsley, 1995). The more the operator is aware of the current and future state of its environment in relation to its goals, the better the situational awareness and the decisions that are made. This also means that experience of the operator can contribute to an increased situational awareness, since faster decision making can be achieved when a situation is recognized (Endsley, 1995; Olsson & Jansson, 2006).
In general it can be stated that a high situational awareness contributes to better performance (Denker, Fortmann, Ostendorp, & Hahn, 2014).

Figure 10 shows the main causes of decreased situational awareness and its related failures. Planning issues appear to cause the most failures, and failures in perceiving information appear to be the highest contributor to accidents (Sandhaland, Oltedal, & Eid, 2015; Denker et al, 2014).

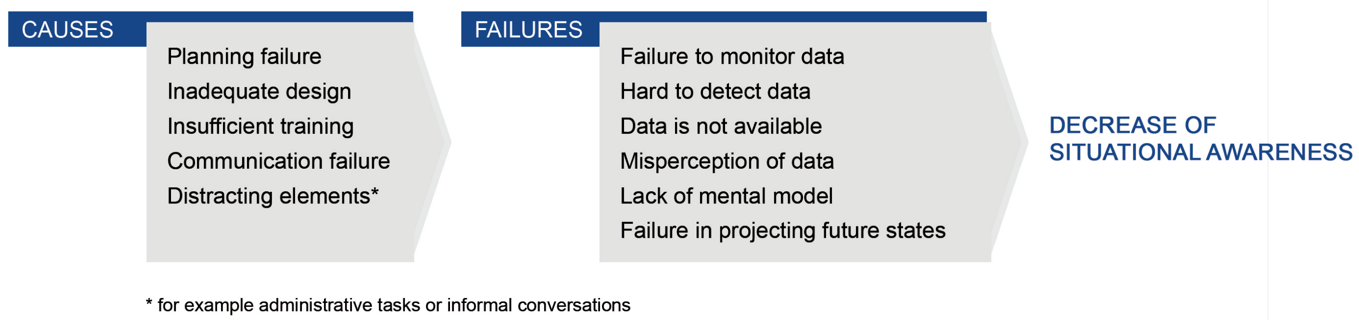

Figure 10: The most common causes and failures regarding situational awareness (Sandhaland et al, 2015).

The increase of automated systems on the bridge has influenced situational awareness since operators rely much more on the systems for situation assessment (May, 1999). By relying too much on system output, without reasoning if this information is correct, this can lead to wrong situation assessment if a system error takes place. Moreover if a function is constantly performed by systems, operators may no longer be able to perform such a function by themselves if the system fails (Parasuraman, Sheridan, & Wickens, 2000). This can be prevented by means of training.

The aim is that the bridge environment supports the operator in maintaining its situational awareness, for example by providing situation specific information. Information that can be easily interpreted from the interfaces will also contribute to an increased situation awareness.
Furthermore it is important to carefully consider whether functions will be automated. In case a function is going to be automated, an appropriate solution has to be taken into account which will serve as the alternative in case of system

failure.
When considering a certain change first an overview of the pros and cons for human-machine interaction have to be outlined. Further insights in the effects can be provided by creating different use case scenarios, of which their appropriateness has to be discussed with actual users. Herein different operational conditions, use situations, and users with differing knowledge levels have to be taken into account. In the end user tests can be performed to validate the assumptions that are done. Testing in the field can also give insight in the influence on the operator's situational awareness.

2.3 Conclusion literature study

Human errors are a common cause in accidents in the shipping industry. Though in several cases the human is essential, because humans are able to understand situations and to react on this by reasoning. System complexity and information overload appear to be high contributors to human errors and thus need to be lowered. By effectively applying human factor principles this can improve the human-machine interaction. In the end this can lead to a lower operator (cognitive) workload, a more efficient workflow, and a better situational awareness.
By deciding to automate processes within the bridge environment the effects on human performance should be analyzed and taken into account. This is important since it is likely that certain changes might affect the performance.

3. USER STUDY

The user study applies to all activities that are performed in order to understand the users' needs, the way they act, and their rationale behind this. Furthermore the user study serves as a way to validate the literature findings in practice.

First a functional and task analysis are performed in order to provide overview about the goals that have to be achieved, and about the general processes that take place at the bridge. This also serves as preparation for the field study.
The field study consists of user observations (during operation) and user interviews. This study is performed to gain insight into the user needs and desires, operational procedures, information exchange between the crew, the use of the bridge environment and its equipment, and the dependencies between different bridge equipment. This serves as a way to identify usability problems, to find out tacit knowledge, and to gain ideas. Tacit knowledge refers to things users are not aware of. For example small inefficiencies or issues in performing tasks may not be noticed anymore because they have become a routine (Wahlström et al, 2016).
Involvement of user experience also gives insight in how much variation or flexibility in the bridge environment is needed to be able to satisfy most of the users. It also serves as a way to predict how users will respond to certain design choices.
The field study will reveal several usability issues whereof the most important ones are presented. By searching for their root causes, it is determined what the underlying processes are that contribute to the causes of these issues. These insights form the basis to solve or even prevent them, and have to be taken into account during bridge development and its strategy.
In the end two use case scenarios are presented which illustrate particular user actions during vessel operation. These scenarios have to provide insight in how future bridge systems can support the user, and are based on insights gathered during the user study.

3.1 Functional analysis

A functional analysis is performed to identify the specific functions that the bridge environment has to support. This will also provide insight in what is needed to operate and control a vessel. This results in a functional block diagram that provides overview of the different functions and their interrelations.

The goals of the user determine the functions the bridge environment has to support. Specific user goals differ per vessel type, but in general it can be stated that the overall goal for an operator is to 'ensure an efficient, comfortable, and safe journey from location A to location B, under all operational conditions'. Specific user goals are specified in the case study in chapter 8.
The overall function of the bridge environment is defined as 'providing means to control the vessel in a safe, effective, and efficient way'. The general functions, subfunctions, and their interrelations are shown in the functional block diagram in figure 11.
Route monitoring relates to the continuous surveillance of the vessels' position according to its route.
Area surveillance is needed to avoid collisions and grounding, and to respond to environment conditions like the weather, tides, and currents. In fact it consists of environment monitoring, traffic surveillance, and the spotting of objects.
During operation the navigation, maneuvering, and operational safety functions are critical for the captain. While alarm management, vessel security, and monitoring functions are critical for the chief engineer.
Bridge functions can change over time due to changing regulations, system upgrades, new technologies, customer demands etc. This will also lead to changing tasks and responsibilities of the bridge crew, for example when the engine room will become unmanned (ABS, 2003). To be able to anticipate on expanded or changing bridge functionalities this need to be taken into account during initial design, for example by making use of the principles of modularity (see also paragraph 6.2: Wheelhouse design strategy).

3.2 Task analysis

Operational goals can be achieved by performing tasks. To create insight into these tasks a task analysis is performed. This will serve as a way to identify design requirements. Moreover during the field study it can be determined if the bridge systems and user interfaces support these tasks in the right way.

Figure 12 shows the most important general bridge tasks. The function to which the task is related is mentioned in parentheses. The figure shows that strategic tasks mainly include route planning tasks, while monitoring tasks mainly relate to navigation and maneuvering tasks. An extensive overview of these tasks is shown in Appendix D.

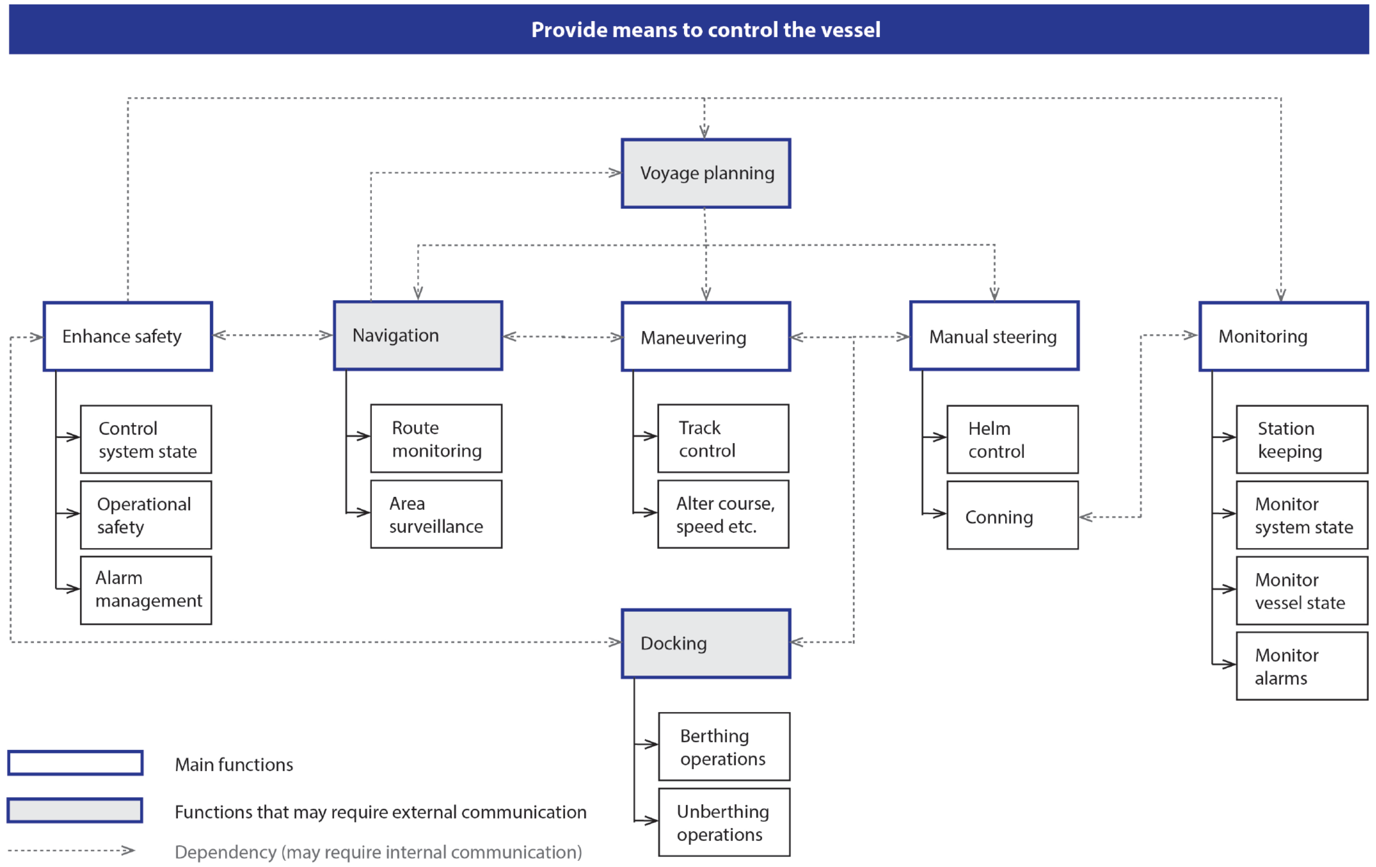

Figure 11: Functional block diagram bridge environment

STRATEGIC

Plan a voyage by means of for example waypoints, courses, etc. (VP)
Calculate estimated time of arrival (VP)
Plot the ship's position (VP)
Capture optimum conditions (VP)
Decide on collision avoidance actions (N&M)
Decide on actions alarm (ES)
Handle internal communication onboard (C)
Reporting (C)

MONITOR

Check own course and speed (N&M)
Monitor route/ track and own position (N&M)
Monitor propeller revolutions and rudder/ thruster angle (N&M)
Observe the outside environment for vessels, land, objects etc. (N&M)
Perceive alarms (ES)
Watch water surface along vessel's side (D)
Monitor machinery/ equipment state (ES)

CONTROL

Control (change of) course, speed and rudder/ thruster position (N&M)
Steer vessel according to rudder/ thruster angle information and course (MS)
Acknowledge alarms (ES)
Control functioning machinery/ equipment (ES)

C = communication
D = docking
ES = enhance safety
MS = manual steering
N&M = navigation and maneuvering
VP = voyage planning

Figure 12: Overview high priority tasks performed at the bridge

3.3 Field study

The field study consists of interviewing the crew and observing them during sailing operations. Also various stakeholders are interviewed in order to gather input from different perspectives; Damen employees of different departments, suppliers of bridge equipment and integrated bridges, chief engineers, instructors of a ship handling simulator, captains of different ships, and other bridge crew members. This provides insight in the stakeholder needs and the constraints and possibilities in the field of bridge design. Extensive information, results, and pictures of the field study can be found in Appendix E: Field study.
Furthermore a questionnaire is send to different captains, which can be found in Appendix F. The questionnaire is filled out by six participants; all captains of tug boats.

The field study has resulted in an overview of the most important usability issues, their general causes, and their root causes. This overview can be found in Appendix G: Usability issue overview.

3.4 Results user study

The most important outcomes of the user study are:

- A lot of different components are included which leads to a cluttered work environment with a lacking coherent appearance
- There is less integration and consistency between the different components of the bridge
- The positioning of information and components can be improved. The first step is to review their priority in consultation with the actual user
- The interaction between the user and the systems can be improved, for example by providing more feedback
- The user can be supported by the interpretation and understanding of the information presented
- The information that is needed on the bridge is dependent from the operating conditions. The system can more respond to these differing conditions.
- The indication and description of alarms have to be presented more clearly, so that this can also be understood by crew with a low knowledge level
- The user has less trust in the output that is given by digital systems on the bridge which is caused by malfunctioning of some systems
- The automation system needs to be better secured in order to prevent that everyone can adjust the initial (calibration) settings
- There is a lot of useful information 'known' by the automation system which can support the user if applied in the right way
- The information shown on displays unintentionally attracts the operators' attention while the focus has to be on the outside environment
- The user prefers to have the most important and frequently used functions available as tangible buttons
- During operating the following senses are important for the captain: hearing (for communication), sight (by monitoring information and the outside environment), and touch (by controlling equipment and devices)
- The current interface structure works not efficient in the dynamic environment of the ship bridge. Crucial time gets lost by searching for the right components and when circuitous actions have to be performed. This leads to reduced safety since the position of the vessel and objects around can change significantly in the meantime.
- User feedback is rarely included during (bridge) development of a vessel

3.5 Root cause analysis

After collecting information about the user and the experienced issues by the user, there is looked at the root causes of those issues. What is the reason or rationale that the things are designed in the way they are? What is the mismatch with the user? By investigating the relationship between cause and effect, the real causes became apparent. The three main root causes that have been found are presented below.

Root cause 1: Knowledge

During development there is not enough knowledge about:

- the actual use situation
- the frequency of use of equipment
- operational conditions and procedures
- human factors
- interrelations of components
- the purpose of different components

Effect: Damen almost makes no demands in the fields of ergonomics, human factors, and appearance; it is often assumed that the supplier will take this into account. Moreover the lack of knowledge results in subjective decision making. In the end this all leads to a bridge that is not fully adopted to its context and that does not fully support the user during operations.

Root cause 2: Business

The Damen company structure and its business philosophy and processes (like standardization, short lead times etc.) lead to several issues:

- Every Product Group takes its own decisions according to bridge development and design
- Every Product Group chooses its own suppliers
- There is laborious communication between different Product Groups and departments
- There is less understanding of working methods and motives between different Product Groups and departments
- Adaptation and customization of standard designs is hard to achieve
- There is limited time to finish a project
- Costs are of significant influence

Effect: There is no overall vision on bridge design which leads to less consistency between different vessel types and on vessels itself. Less effort is put in providing that extra advantage to stand out in bridge design. Moreover there is not taken advantage of joint purchase and knowledge sharing between departments on a regular basis, so the wheel is frequently re-invented.

Root cause 3: User involvement

The main issues according to user interaction are:

- There is no direct contact between the design team and the user
- Users are not used as validation during the design process
- There are a lot of user opinions and it is hard to decide which ones should be taken into account
- Decisions made according to user feedback are not communicated to them

Effect: The bridge is designed from technical perspective instead of user perspective. There is also less insight in the use situation and in the real operational needs. This results in a bridge that does not support interaction with the user in the most effective, efficient, and satisfactory way.

3.6 Use case scenarios

The user study gives insight in the current interaction on the ship bridge and, in particular, in the defects herein. Therefore two use case scenarios are drafted, which show the preferred performance of the total bridge system in case of operational support, see figure 13 and 14. The scenarios are displayed by means of a diagram wherein the roles of the different actors, information sources, and interactions are identified (Javaux et al, 2015).

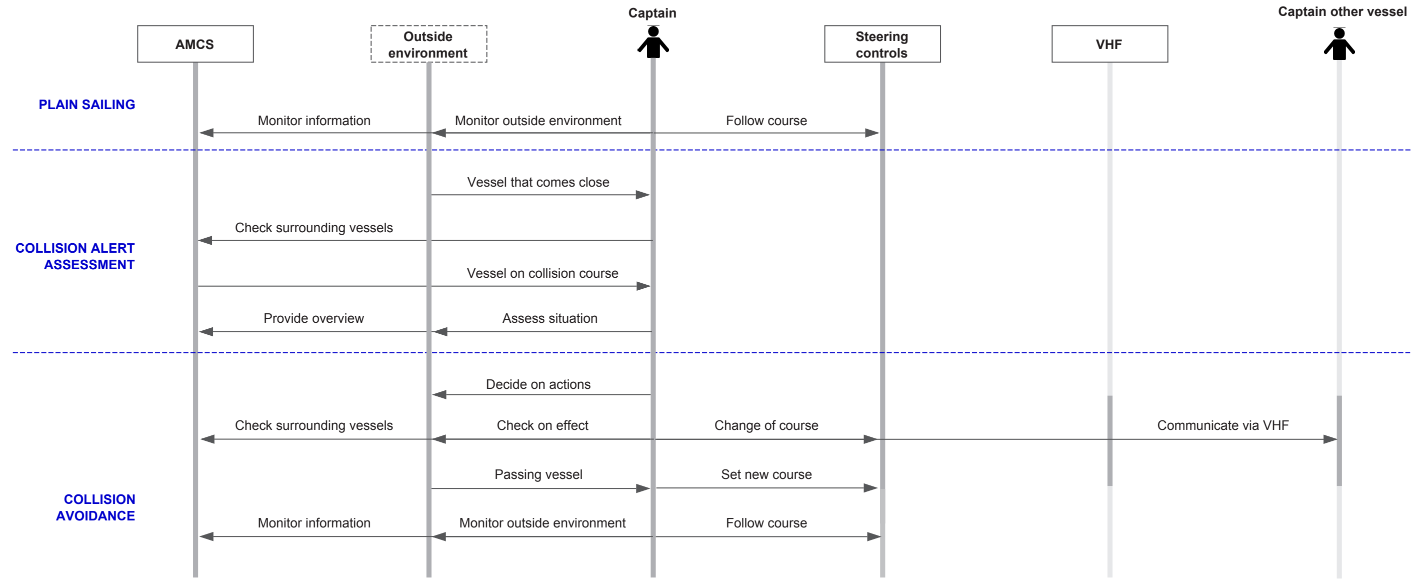

Figure 13: Collision avoidance scenario

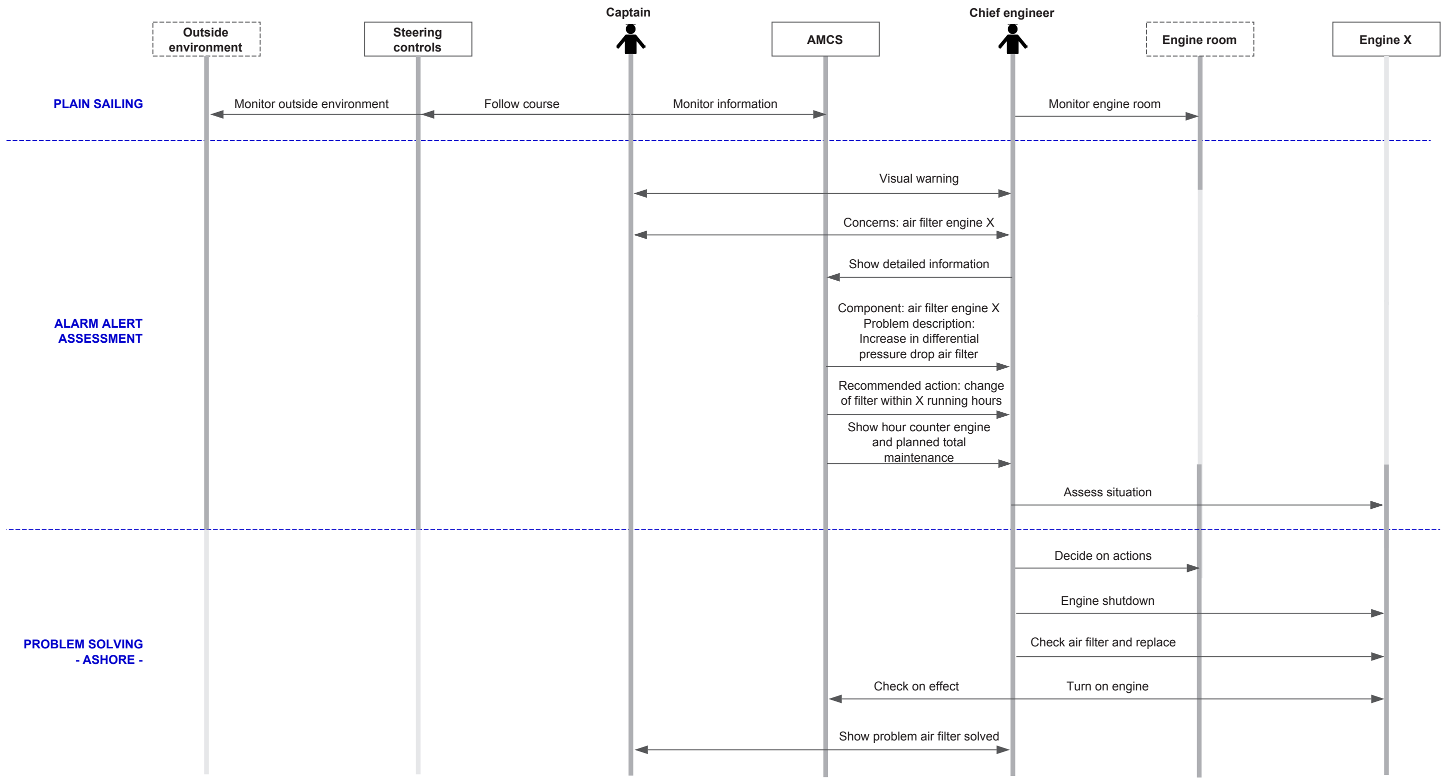

Figure 14: Alarm handling scenario

3.7 Conclusion user study

The bridge environment is not designed as an integrated entity, for example every display has its own input control device. This leads to a cluttered work environment which requires a lot of visual scanning of the operator in order to find the right equipment and information. Moreover a relatively large amount of actions have to be performed by the operator to achieve its goals. So to support efficient human-machine interactions and operations, the current bridge environment can be improved.
The bridge usability issues that became apparent are caused by lack of knowledge about human factors and operational demands within Damen. Damen also needs to make specific demands on bridge design (for example on the ergonomics), and needs to have more direct contact with the user, in order to improve the bridge layout and its interfaces. Moreover smart collaboration with suppliers is needed to prevent that the design of Damen bridges gets constrained by the design of the equipment of suppliers.
To tackle the business causes, a good start can be made by creating an overall bridge vision or wheelhouse design strategy. Hereby the main drive for changes should be the user (or client) and not cost reduction.

It is likely that functions and tasks will change in the future. For example some tasks may be operated by automation systems instead of humans. Therefore it is useful to focus on user goals during the design process rather than on the exact fulfilment of tasks. After all the objective is to create a wheelhouse that has a supportive function in achieving those goals (Wickens et al, 2004).

Overall it can be concluded that the wheelhouse and its interfaces should reduce visual scanning for components, reduce time spent in menus, and reduce information overload, in order to support looking outside, and maintaining situational awareness. This should lead to efficient and safe operations. To achieve this the bridge has to be developed by means of a standardized and holistic approach.

4. FUTURE STUDY

By developing products it is useful to gain overview about current (competitive) products and future possibilities. Market research about current solutions provides insights in their strengths and weaknesses and also might provide new ideas. By exploring of new technologies and innovations, future possibilities and opportunities can become apparent. This is also important since the product is going to be used in the future. To be able to respond to future changes, also information about current and future trends can be gathered on relevant topics.
This all will result in ideas and information that can serve as input for product development.

A market research is performed to gain overview about current ship bridge solutions and interaction technologies. This research can be found in Appendix H.
In this section future ship bridge concepts and interaction technologies are investigated. Hereby the most important findings and similarities are presented.
In the end a summary of global trends and trends in the maritime industry is given. Herein the trends are included that might influence ship bridge design or its development in the future.

4.1 Future ship bridge concepts

Several large players within the maritime industry have presented their future vision on bridge design. This shows the advantages new technologies can offer within the bridge environment. It also implies that they have noticed a need for more integrated ship bridges that support the user in performing safe operations.
Figure 15-20 show three different future bridge (system) concepts, respectively: the future ship bridge concept of Ulstein (n.d.), the maritime control system of Kongsberg Maritime (NCE Micro- and Nanotechnology, 2016), and the adaptive bridge system of the CASCADe project (n.d.).
They all have taken the human-machine interaction as basis for their design, whereby user experience and human factors play an important role. Moreover they approach the ship and its bridge as an interconnected system.
They all share the aim to simplify tasks and systems, to enhance safety, and to support the user in keeping its eyes on the outside environment as much as possible. Also several similarities can be found between the concepts itself. First the use of large displays devices and more intelligent systems becomes apparent. Also a wide variety of screen technologies are applied: touchscreens that can be controlled by means of handles, touch displays with multi-touch or drawing capabilities, and projection of information by means of head-up displays. Furthermore the concepts are more configurable to different situations and users.
Also in other (related) industries attention is paid to future interaction concepts. For example Thales presented the cockpit of the future: Avionics 2020 (Thales, n.d.). Concepts of the aviation and car industry can even serve as a useful inspiration for maritime interaction concepts since they are ahead of the maritime industry.

Figure 15 and 16: Ulstein bridge vision (Ulstein, n.d.)

Figure 17 and 18: Future maritime control system Kongsberg Maritime (NCE Micro- and Nanotechnology, 2016)

Figure 19 and 20: Use of touch screens within the adaptive bridge system of the CASCADE project (CASCADe, n.d)

4.2 Interaction technologies

Several promising and potentially useful technologies regarding human-machine interaction will be presented below. Inspiration is gained from applications in related industries like the car-, aviation- and computer gaming industry. Since several screen technologies are already mentioned in paragraph 4.1, these will not be described below.
First the technologies will be outlined, whereafter their possible application and usefulness within the bridge environment is considered.

Multifunctional control wheel
A multifunctional control wheel like a jog dial (figure 21) is currently applied in many car interfaces, to quickly navigate through its different functions (by turning) and to select them (by pushing). In this way the music can be controlled, a final destination can be set, or a call can be initiated. By knowing its functions the user can control the wheel while keeping its eyes on the outside environment.

Figure 21: Jog dial within an Audi car i nterface (Audi, n.d.)

Multi-touch control
Mattheus Krenn proposes a new user interface design with multi-touch control, see figure 22. All functions of the display device can be controlled from every position where the fingertips are placed on the screen. Different functions are related to the amount of fingers and the distance between the fingers touching the screen. Several modes require bigger or smaller movements according to the accuracy that is needed for the relevant function (Krenn, n.d.).

Figure 22: Adjusting temperature by using four fingers (Krenn, n.d.)

Virtual reality
Virtual reality is a technology to replace reality by a computer simulated environment. This virtual environment appeals to the human senses, like sight and hearing, and makes the user part of this potential reality. By means of example display devices or glasses the virtual representation is shown to the user. This means that it is possible for the user to interact with this potential reality or aspects therein, and to completely get involved (Damgrave, 2014)[1].

Augmented reality
Augmented reality places virtual information into the real world. This information can be added by means of projection. Applications of this technique are for example a head-up display (HUD) whereby information is projected on a transparent area, see figure 23.

Figure 23: Garmin head-up display in use (Garmin, 2013)

Gesture control
The technology of gesture control makes it possible to interact with virtual objects by making hand movements. Infrared cameras track a persons' movements which can be linked to different functionalities of the system.

Speech recognition technology
The speed recognition technology enables the automation of (simple) tasks by making it possible to let machines respond to human voices (Juang & Rabiner, 2004). Voice control is nowadays applied in computers, phones, and displays in cars.

Eye tracking technology
The eye tracking technology measures the eye activity in order to determine where someone is looking at. The reflection of a (infrared) light source on the pupil is captured by a camera. In this way the direction of gaze can be determined and also visual paths on interfaces can be analyzed (EyeTracking, 2011).

4.2.1 Application in bridge environment

How useful these technologies might be within the bridge environment will be considered below.

A multifunctional control wheel can be applied as input device on the bridge. Since a lot of different functions can be allocated to it, this can reduce the amount of hardwired buttons. Its shape makes it also possible to control the wheel under rough weather circumstances.
Virtual reality can be used in a test- or training environment to allow the operator to get already familiar with the bridge environment and its equipment.
Augmented reality can be used by projecting situation specific or critical information in the operators' line of sight to support its operational procedures. The advantage hereof is that the operator only has to focus at one point to perceive both system information and information from the outside environment.
Gesture- and voice control can be used to control different functionalities on the bridge, like the central alarm system or to give the navigational system orders regarding the route the vessel has to go. Moreover both technologies enable the operator to look outside while controlling the systems. In the end this can result in less physical controls. However the usefulness and feasibility in the bridge environment need to be investigated further. For example the influence of ambient noise on voice control, and the distraction it may cause should be investigated.
Eye tracking can be used for safety purposes to check if attention is paid to the right parts of the bridge system, e.g. in case of fatigue.

Technologies that seem promising regarding several captains are augmented reality, 3D presentation of other vessels and their tracks, and 'Google street view' at sea to be able to view certain regions or harbors in advance. This could provide better insight in situations with other ships and allow for better preparation. Though in case of augmented reality there are doubts about the influence it will have on the sight of the operator and about the sustainability of the application.

1 Reference from Blackboard University of Twente (not publicly accessible)

4.3 Trends

First a couple of global trends are described that are of influence on the entire maritime industry. Hereafter more specifically is looked at global- and technological trends that will affect the ship bridge environment.

Trends that affect the maritime industry:

- **Globalization of markets**, which increases the overall competition (Wahlström et al, 2016)
- **Climate change and the increasing public awareness**. Exhaustion of natural resources results in the need for new sources and the need to reduce consumption. Moreover shipping lanes in Arctic regions become available due to melting pole ice caused by climate change (Wahlström et al, 2016).
  The environmental awareness brings along the need to reduce emissions and risks by the use of alternative energy sources (Wahlström et al, 2016; Lloyd's Register, QinetiQ & University of Southampton, 2015).

Lloyd's Register et al (2015) outlines several developments that affect the bridge environment:

- **Rapid technological change**
  Technological change influences the way ships have to be operated and controlled by the operator. Systems and machinery need to operate in a more automated and remote way which leads to a reduction in the amount of crew on board (Mallam & Lundh, 2016). Overall it can be concluded that this has led to a changing role and responsibility of the operator on the bridge.
- **Big data management and analytics**
  The increasing use of managing and analyzing big data makes it possible to provide data-driven services in real-time, like (remote) monitoring of vessel performance. Systems take over the process of data interpretation and serve as interface between humans and machines. By enabling the continuous receiving, analyzing, and sharing of relevant information, it also becomes important to protect this data and its related systems and equipment against external interferences.
- **Sensors**
  An increasing use of sensor technology is expected which includes wireless- and remote sensor technology. Equipment on board will have the ability to control its own status and will be able to warn the operator if maintenance is required. So the technology will move towards a more proactive approach to anticipate on future scenarios. Sensors will also contribute to collect and transfer big data.
- **Communication**
  It is expected that the need to transfer (a large volume of) data between ships and the shore will increase. To make this possible the current wireless communications like VHF installations, satellites, and Wi-Fi need to be improved. Moreover attention need to be paid to prevent external interferences, since this can lead to misleading situational awareness or can threaten the proper working of systems.
- **Human-machine interaction**
  New interaction technologies are expected which enable new ways of system interaction, for example by responding to personal preferences. Though, this will first require the approval of Classification which might be a challenging and long-term process.
- **Smart ship**
  The aim of smart shipping is to improve the way ships are managed, operated, and maintained by applying new technologies and automation. A shift towards more autonomy and autonomous shipping will gradually take place. In the end this may lead to unmanned ships that are remote controlled from the shore. See for example the future operator experience concept ('oX') of Rolls-Royce (Rolls-Royce, 2016).

4.4 Conclusion future study

User interaction, user experience, and human factors will play a more important role in future ship bridge development. Technologies that are likely to become useful within the bridge environment are projection, tangible and non-contact user interfaces, haptic technology, and motion simulators (Wahlström et al, 2016). Moreover an increasing use of large display areas and wearable devices can be expected.

The maritime industry will move towards smart, connected ships with more automated functions. Hereby cognitive overloading due to increasing complexity of systems and the amount of information provided has to be prevented.
The application of new technologies will lead to a ship wherein the human operator will delegate more responsibility to smart devices; ships will be operated differently than nowadays. This will also affect the education of engineers and captains. Moreover issues according to cybersecurity and safety will become more important.
But since technologies are developed faster than prescriptive regulations, it will take time before the industry will be ready. Also the process of the implementation, acceptation, and getting used to new technologies and approaches will be time consuming (Lloyds Register et al, 2015).
Overall it can be stated that the future study gives insight in the technological boundaries, and in whether technologies are already at a stage that they can be applied within a maritime work environment.

5. RESEARCH SCOPE

During the Foundation phase different topics regarding the bridge environment are explored. This has provided insight in the strengths and weaknesses of current designs and their causes.
In the next phase a bridge concept will be developed. This concept will be elaborated on basis of one focus area, since this is the most useful for Damen. To determine the research scope the different usability issues within the wheelhouse are taken as starting point. The factors that are expected to be the most influential on improving usability, and that apply to a variety of vessels are:

1. Reach and arrangement of components
2. Information supply, structure, and presentation
3. Integration of the (interface) design and its underlying design process
4. Adaptation of different users and use situations

There will be focused on the information supply, structure, and presentation since improvement of this area seems to have the most added value for Damen at this moment. Considering the trend that automation and digitalization of the bridge environment will keep increasing, it is useful to pay attention to the user interface design and cognitive ergonomics. Hereby also different use situations, users, related components, positioning of those components, and the Damen identity are taken into account.
The research objective is formulated as:

'Compose an integrated design philosophy to decrease the system complexity and increase the interfacing performance'.

This has to serve as a guidance for future wheelhouse development within Damen.
An overview of all areas of interest and the research scope is shown in Appendix I: Areas of interest.

CONCLUSION FOUNDATION

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The application of new technologies will lead to a ship wherein the human operator will delegate more responsibility to smart devices; ships will be operated differently than nowadays. This will also affect the education of engineers and captains. Moreover issues according to cybersecurity and safety will become more important. But since technologies are developed faster than prescriptive regulations, it will take time before the industry will be ready. Also the process of the implementation, acceptation, and getting used to new technologies and approaches will be time consuming (Lloyds Register et al, 2015).
Overall it can be stated that the future study gives insight in the technological boundaries, and in whether technologies are already at a stage that they can be applied within a maritime work environment.

PHASE II
SPECIFICATION & DESIGN

The aim of the Specification and Design phase is to achieve the goals as formulated in the conclusion of the Foundation. In fact the insights of the previous studies have to be translated into specific results that are useful for Damen.
This phase describes the processes and background information to come to: (1) the Damen wheelhouse design strategy, (2) a user interface design philosophy, and (3) a Damen interface concept for a specific vessel type. The latter is achieved by means of performing a case study for an Azimuth Stern Drive (ASD) tug. The concept that is developed will be evaluated by actual users, whereafter an iteration is performed.
The results of these processes are presented in the Research synthesis.

6. DAMEN WHEELHOUSE DESIGN STRATEGY

A Damen wheelhouse design strategy is developed to support more coordinated development and to help to approach the design in a simplified way. The strategy has to support coherence and interaction between the different aspects of the design (process), rather than focusing on specific components of the design. Moreover it has to contribute to achieving design goals by offering techniques and tools to work in a more effective and efficient way, without limiting the designer.
The strategy has to facilitate decision making on basis of a clear rationale, and good communication between Damen and other stakeholders during the development process. By doing this it will support Damen in becoming outstanding in ship operation. This all should contribute to an increased usability of the vessel, and safer operations.
The strategy also has to contribute to the long term strategic goals of Damen: increase the quality of their products, bring their cost price down, and shorten their lead time.

In this section the strategy foundation is determined first, which serves as a starting point for the subsequent processes. Moreover it gives insight in the context of the strategy and its constraints.
Hereafter the key values of the strategy are outlined, to provide background information about the actual strategy. To support the application of the strategy within the Damen organization, all aspects are included into a strategy roadmap. This roadmap will serve as guidance during the development of a Damen wheelhouse concept design.

6.1 Strategy foundation

The structure of the concept development is based on the course of a general design cycle. The choice of this design cycle is outlined first. Hereafter the context of the wheelhouse design (strategy) is clarified.

6.1.1 Design cycle

The structure of the wheelhouse development is based on the three main design phases described by the design method of Ullman (1992), see figure 24. This method is chosen since several principles that are included in the method are useful for Damen in approaching their wheelhouse development. These principles are outlined as follows:

- Attention is paid to the initial design stages whereby early decision making is supported. Since the wheelhouse is (part of) a complex product it is very important that the first stages of the design process serve as a reliable and decent foundation for the subsequent stages. Furthermore issues should be tackled as early as possible in the design process, because design changes require less effort during early development and it is easier to anticipate hereon at this stage.
- Principles of concurrent engineering are applied: several design processes and activities are performed at the same time. Damen wants to reduce the lead time of their vessels, and performing several processes in parallel will contribute to achieve this.
- The Ullman design cycle provides a framework for making decisions, so decision making, the way decisions can be taken, and the evaluation of the consequences hereof are supported. It is important to support designers in the decision making process, since decisions can be crucial for the success of a product (Eger et al, 2010). Moreover the root cause analysis of paragraph 3.5 reveals that the decision making process within Damen can be improved.
- The design is regularly reviewed in order to evaluate decisions that are taken. Damen wants to increase the quality of their products. By regularly reviewing a design and the underlying decisions that are taken during its development process, this will contribute to a better quality of the product in the end.
- The overall design problem is decomposed into smaller subproblems, which makes it easier to manage the overall problem. This is useful for complex products or environments, like the bridge and wheelhouse environment.

However it might be good to keep in mind that early decisions or choices may have major consequences for sequential processes later on. This can be a risk if future processes are not foreseen. Prior experience is therefore important to take into account. Furthermore the parallel processes and subproblems of complex designs need to be well coordinated, otherwise it might lead to undesired situations.
More explanation on these topics is given in paragraph 6.2.1: Key values strategy.

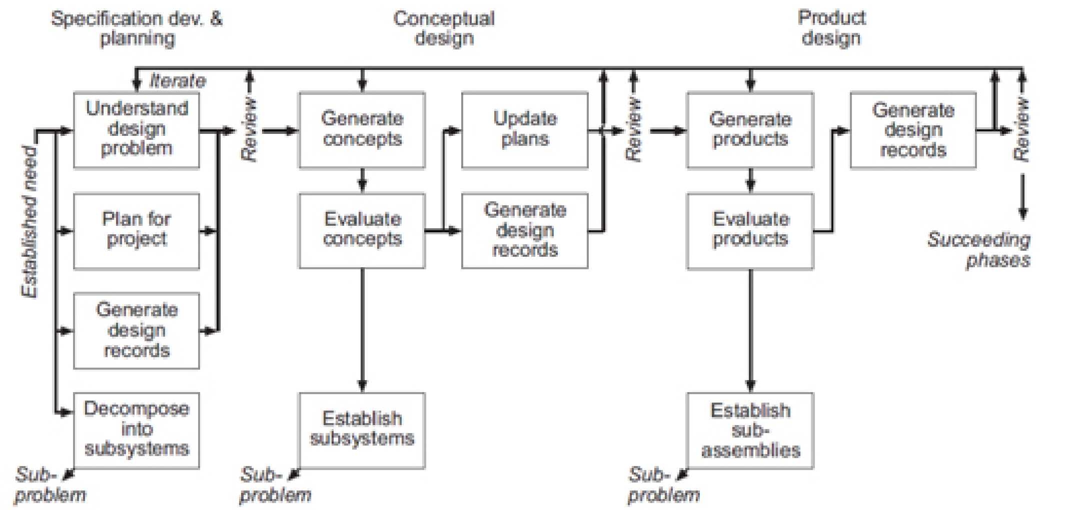

Figure 24: Design cycle as defined by Ullman (1992)

6.1.2 Total context

To come to an integrated ship bridge concept, also the surrounding environment of the bridge has to be taken into account: the wheelhouse. Since several aspects of the wheelhouse design influence the design of the ship bridge significantly, the strategy is composed from the viewpoint of the entire wheelhouse. For example the wheelhouse area dictates to a large extent the available space and the positioning of the equipment components on the bridge. The dependencies between a vessel and its wheelhouse are shown in figure 25.

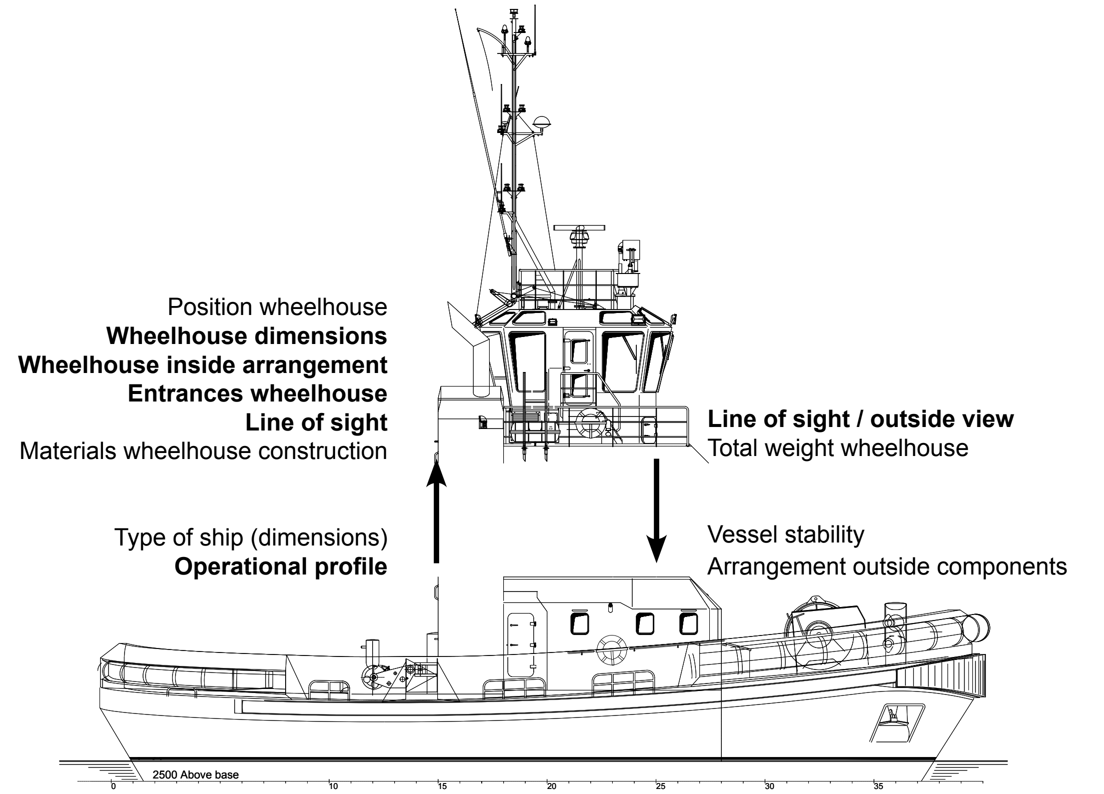

Figure 25: Dependencies between vessel and wheelhouse (ASD tug 2310 side view)

From figure 25 it can be concluded that the wheelhouse and bridge design are more dependent from the vessel design than vice versa. Therefore the vessel design, including the outer construction of the wheelhouse, is taken as starting point for the wheelhouse design. Hereby the wheelhouse design applies to the interior wheelhouse design, like crew seats, different workstations, bridge consoles, systems, components, and the integration hereof.
The operator's line of sight from the wheelhouse is an important (Class) requirement and will serve as an important guideline during both vessel development and designing of the (interior) wheelhouse design.
So the wheelhouse design strategy is related to the total ship building strategy. By knowing the constraints, it will be possible to perform a lot of stages of wheelhouse development parallel or separate to vessel development.

6.2 Wheelhouse design strategy

The strategy contributes to standard wheelhouse development instead of custom development. This means that the application of the strategy will lead to a standard wheelhouse concept that can be adjusted on basis of customer wishes. Previous experience shows that customers often order a standard bridge as supplied by Damen. Custom development is rare since customers do not have much requirements according to the wheelhouse.

6.2.1. Key values strategy

Key values are aspects of the strategy that play a crucial role within the development process. The strategy should enable the management of those aspects. Further information about the relevant values and their management is given below.

Iteration
Iterative development means that (parts of) the design is iterated while under development, in order to improve the design at an early stage in the design process. Iterations are often performed on basis of feedback acquired during (user) testing and/or evaluations. A combination of this feedback and the quality of the design can serve as a guideline for the amount of iterations needed.
Several evaluations and subsequent iteration cycles will be proposed within the strategy.

Concurrent engineering
During ongoing projects within Damen there is often less time to perform innovation, iteration cycles, and testing, while they are essential factors in developing market changing products. Though by performing these processes in parallel and separate from specific projects, there should be more time available. In this way the processes could be performed more thoughtful.
In general it can be stated that performing processes in parallel contributes to better interaction, which leads to an improved quality of the processes and better products in the end (Eger, Bonnema, Lutters & van der Voort, 2010). That is why the strategy will propose the application of concurrent engineering principles.

Design reviews
By means of a design review decisions and their consequences are evaluated (at an early stadium). It serves as a way to discuss the progress of a project, process, or activity. Hereby also decisions can be taken about the subsequent steps: to continue, to iterate, or to end the relevant activity.
During design and development stages it also serves as an important moment to evaluate the quality of the product and to determine if the preferred level of quality is reached. Several design reviews will be proposed within the strategy.

Decision making
To enable decision making on basis of knowledge, the performing of thorough research is taken into account within the strategy. Though, also involvement of employees from specific disciplines will be needed to support this. For example people with a background in human factors.
The evaluation of the consequences of decisions that are taken are supported by performing design reviews.

Early development
Figure 26 explains the importance to pay more attention to the first stages of the design process. At the end changes are expensive and costly, so the process needs to be managed in such a way that most changes can be made early. This can for example be supported by performing iteration (Ullman, 1992). By performing extensive research and testing at the beginning of the process, this can provide insights in the needs, feasibility of ideas and concepts, and project risks in an early stadium as well.

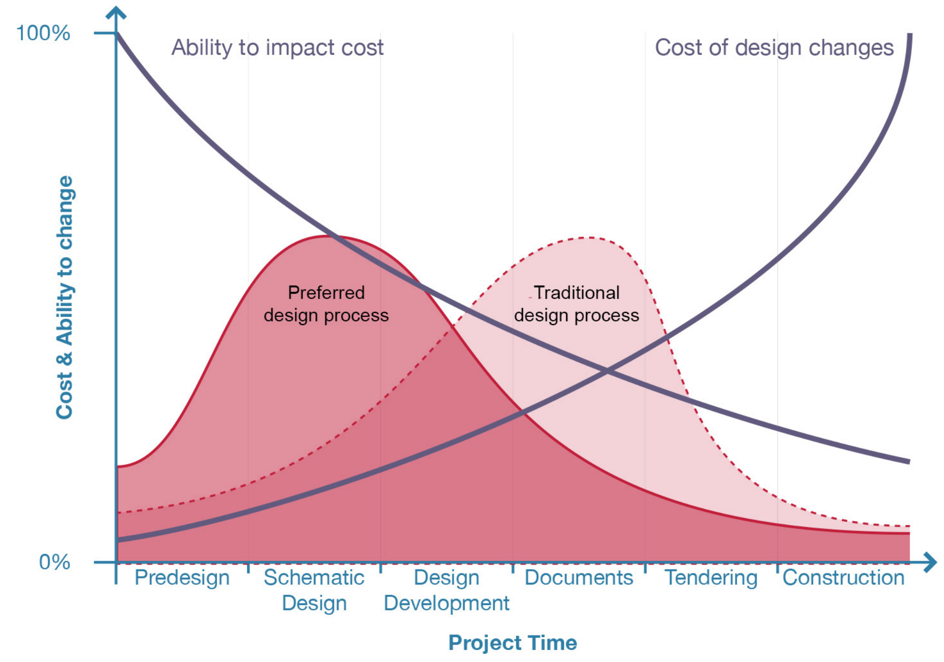

Figure 26: Influence of design changes during the design process (MacLeamy, 2010)

Innovation
Insights in the user tasks and needs usually leads to adjustments to existing designs: incremental design solutions. Users relate their experience to current practices and are often not aware of the technical trends and future opportunities (Schilling, 2013; Kristiansen, 2014; Wahlström et al, 2016). This can be illustrated by a quote made by Henry Ford in the Thirties: "If I had asked my customers what they wanted, they would have said a faster horse".
Since Damen's objective is to generate solutions for future purposes also innovation projects need to be performed and included. This will contribute to the development of new or radical design solutions that can be introduced via the principle of 'technology push'.
The proposed innovation projects are performed in stages, in order to evaluate per stage if it is still useful to continue the project. This is done on basis of different criteria like added value for the customer, competitive advantage, and implementation costs.

Involvement of the user
User involvement is important to validate the design and its usability (Costa et al, 2015; Kristiansen, 2014; Wahlström et al, 2016). They are in involved at several stages to:
- acquire insights in the context of use
- test if the design meets the user needs
- collect product feedback

Testing
Testing with (simplified) prototypes can be applied to test a current design, to test adjustments to a design, or to test the appropriateness of new functionalities. It serves as a way to validate the design or to give insight in choices that are considered. Low-fidelity prototypes (like paper prototypes) can be used to illustrate design ideas, screen layouts, and design alternatives, and give a first impression of the design. High-fidelity prototypes (like working prototypes) can be used to test the actual functioning of a system or component. These prototypes also help to gain insight in the production and possible problems that may arise during production.
Several design evaluation sessions are proposed since the feedback that is acquired can help to meet the user needs, and proposed objectives and requirements.

Product feedback integration
Collecting product feedback from user perspective can support the improvement and development of wheelhouses in the future by means of the 'market pull' principle. Feedback from customers can for example be collected by Services during the first year after delivery of a vessel; the warranty period of a Damen vessel.

Product quality
The aim is to develop qualitative products. To provide more guidance in achieving this, several parameters are drafted: elements that have the focus during design. Parameters can be defined with different priorities and for different themes, like human-machine interaction or anthropometry. In the field of HMI parameters can be system feedback, system response time, readability, field of vision wherein critical information is presented, etc.
The aim is to keep track of the parameters during development in order to achieve a required level of quality. This can be done by defining the parameters as measurable requirements which are checked several times during the development process, for example during design reviews. In this way the level of quality can be assessed and optimized before proceeding to a next stage.

Modular product architecture
A modular product architecture enables the development of a wide variety of products by making different combinations of standard and custom components (Schilling, 2013).
Currently this practice is applied on ship development level, though by applying it to an even more detailed level the benefits of this strategy can be maximized. By applying modularity to the components of the wheelhouse, bridge, and graphical user interface more consistency can be achieved, a higher quality and reliability can be achieved, and costs can be reduced. By providing a standard platform for all Product Groups also the wheelhouse development time may decrease.
However joint purchase, independent from the Product Groups, will be required to achieve this. This structure is proposed by the strategy but might require a large change in how procurement is currently approached within Damen; per Product Group.

Styling
Activities in the field of design and styling are supported by the strategy. By paying attention to design and styling a more user friendly and integrated design of the wheelhouse can be achieved. It also contributes to a coherent appearance of the wheelhouse and its components over different vessels. Moreover it can help Damen to increase their brand awareness, if for example a Damen identity is developed and applied.

6.3 Strategy roadmap
A strategy roadmap is developed to serve as a guidance by applying the wheelhouse design strategy. Herein also the key values of the strategy are taken into account. The roadmap provides a framework of activities that can be performed during wheelhouse development, see figure 1: Strategy roadmap of the Research synthesis. Its content allows to develop the wheelhouse in a descriptive way, since there is no prescribed path that can be defined and followed (Dankers & Lutters, 2010). It shows different paths that lead to a common goal: the development of a modular, integrated wheelhouse standard with a Damen identity, which can be offered directly to the customer. The use of the roadmap should support the development in an optimal way.

To make sure the strategy roadmap fits within the business of Damen, the internal organization is taken into account. See also the organization chart of a Damen business unit in Appendix J. Furthermore the strategy is peer reviewed by Damen employees and their feedback is taken into account.

6.3.1 Follow up roadmap
The roadmap focusses on the processes prior to the order or the building of a vessel. Figure 27 shows the processes that are likely to follow, once the activities of the roadmap are completed and a wheelhouse concept is developed.
The customer is able to have influence on the wheelhouse design during these follow-up processes. Hereby the wheelhouse concept is taken as starting point.
In case of a fully customized bridge the customer can already be involved at an earlier stage, for example during the idea or concept generation. To be able to include customer specific requirements they have to be translated into measurable criteria or quality parameters. These parameters have to be checked during the design review to ensure that customer needs are met.

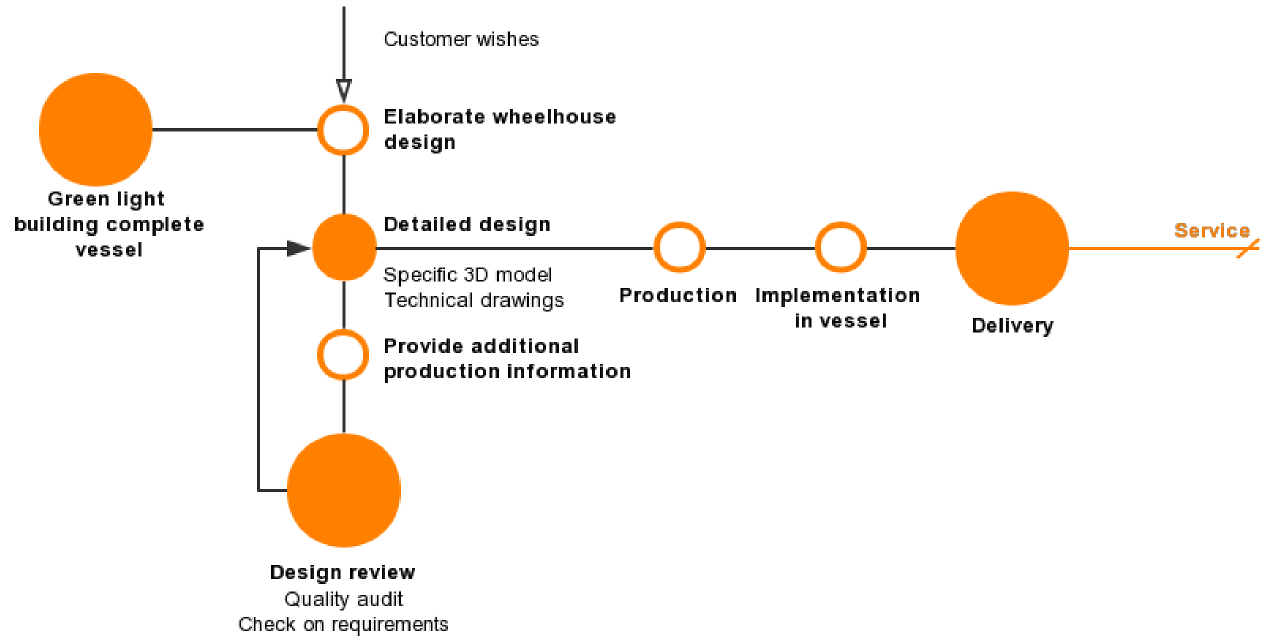

Figure 27: Follow-up processes strategy roadmap

6.4 Conclusion Damen wheelhouse design strategy
The proposed design strategy proposes a change in the way how wheelhouses and bridges are developed within Damen. Wheelhouse development has to be performed in a more centralized way, so it has to be approached from Damen broad perspective rather than per Product Group. Hereby the functions of the different vessels are leading, but there is benefitted from similarities in components, appearance, and production of the wheelhouse.
By designing the wheelhouse from user perspective other expertise will be needed to support this process, like interaction designers, graphic designers, ergonomic experts etc. Their perspective and way of working will bring along new activities, like drafting usability requirements or developing an image library as basis for the Damen user interface design. This will also require the frequent performance of design reviews and testing of (parts of) the design by means of prototypes. Decisions can be made on basis of these tests, reviews, and user insights, so the strategy will also influence the way how decisions are made. Personal preferences have to be left out as much as possible in order to allow for objective decision making.
The strategy will demand more regular interaction with the user. Also more effort has to be paid to acquire feedback about the design and to take this into account in future designs.
Once the wheelhouse concept (or parts of it) are developed, it can serve as a solid base to take the design to the next level.

It might take some time to put the strategy into practice within the organization. However by taking the key values of the strategy as starting point it will already help to create a more thoughtful and consistent wheelhouse design which fits the company. It also serves as a first step of the process to create a complete and integrated user experience within a Damen wheelhouse.

7. USER INTERFACE DEVELOPMENT

In this section the process to come to a wheelhouse user interface concept is described. The concept wherein this results is presented in the separate Research synthesis.

A user interface (UI) is composed of all components that allow for interaction between the user and a system, for example input controls and display devices. Different technologies provide a basis for the offering of different functionalities. During use positive emotions should be provoked by the users. This can be achieved by a user interface that is easy to use and to understand, that supports the user in performing its tasks, and is experienced as pleasant to work with.
An important objective of the wheelhouse UI is that it has to support operational safety. For example it should enable the operator to spend less effort on information search and managing controls, and thus encourage to pay more attention to the outside environment and to perform tasks (Olsson & Jansson, 2006).

First the card sorting method is applied to gain insight in the optimal organization of information items of the wheelhouse UI. This results in different information priority matrices that show the relative importance and frequency of use of these items.
The insights gathered serve as input for the general information structure, and the framework for the graphical user interface, as presented in the Research synthesis.

7.1 Card sorting method

A lot of information is available within the wheelhouse. The aim is to determine the best way to offer this information to the user, therefore an information architecture will be set up.
The success of an information architecture depends on how well the structure matches the user's expectations (top-down influences) (Wickens et al, 2004). So to provide a structure that is consistent with the user's mental model, the user is involved in the process of categorizing the information (as also proposed by the strategy roadmap). This is done by means of the (open) card sorting method. This method will also help to reveal the priority, relationships, and interdependencies between the different information items. Moreover it will provide insight in where users will look for certain information. However the results are not leading but will be taken into account in determining the information structure.

First an overview is made of the information that is currently shown or possible to show within a ship's wheelhouse, see Appendix K: Information items. Information that is mandatory by Classification can be found in Appendix L: Information mandatory by Classification.
Sticky notes with the information items are used as starting point for the card sorting sessions. During a session the notes have to be logically grouped by the user whereby the groups have to be named. The priority of the items can be indicated by placing them in a particular order. Information that is missing can be added with new notes. Information that is indicated as irrelevant can form a separate group. During the sessions also several questions are asked to the participants about choices that are made and the reasons why they are made.

7.1.1 Implementation card sorting

Captains as well as chief engineers will participate since they are both frequent users of the systems within the wheelhouse. In the end four captains and two chief engineers did participate.
Figure 28 and 29 give a short impression of the results of a card sorting session.

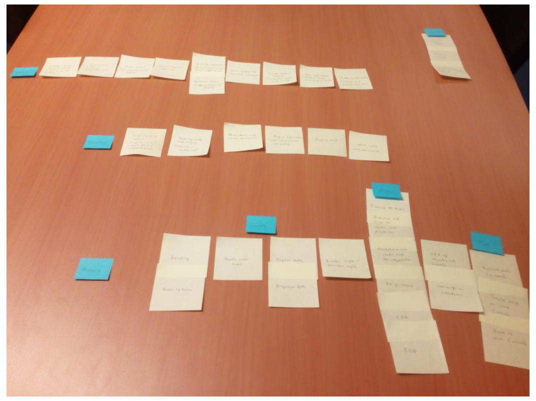

Figure 28: Grouping of information items

Figure 29: Drawing of layout conning information

7.1.2 Results

The card sorting sessions have provided various insights, which are presented below.

By analyzing the differences in information necessities on several vessel types, it became apparent that the information that is needed is mainly directed by three aspects: (1) the vessel's operational profile, (2) the vessel's operating area, and (3) the distances the vessel has to travel. All these aspects influence the importance and the kind of information that is required by the captain and chief engineer. For example some information might become more crucial when making a long journey.
So by displaying the results of the card sorting sessions, first a rough distinction is made between vessels that operate in sheltered waters and vessels that operate in exposed waters:

- **Category 1 sheltered waters**: the vessel is mainly operating in the same area close to land, in harbor-, coastal-, and terminal areas and travels short distances. For example a tug
- **Category 2 exposed waters**: the vessel is mainly operating in different areas at sea and travels long distances. For example a platform supply vessel

The main findings that are acquired during the card sorting sessions are summarized by means of information priority matrices. These overviews serve as input for composing the information structure, and support the decision making about which functions have to be included.
The matrices of figure 30 and 31 show the importance and frequency of use of information items for both vessel categories, and are reasoned from captains' perspective. The matrix of figure 32 shows the information priorities and importance reasoned from engineer's perspective, independent from a vessel category. Information that turned out to be irrelevant is left out (see Appendix M: Results card sorting), so only information that is experienced as useful is included in the figures.
Optional information relates to information that is included because certain optional components are included. Extensive information relates to information that is not a necessity but is 'nice to have'.

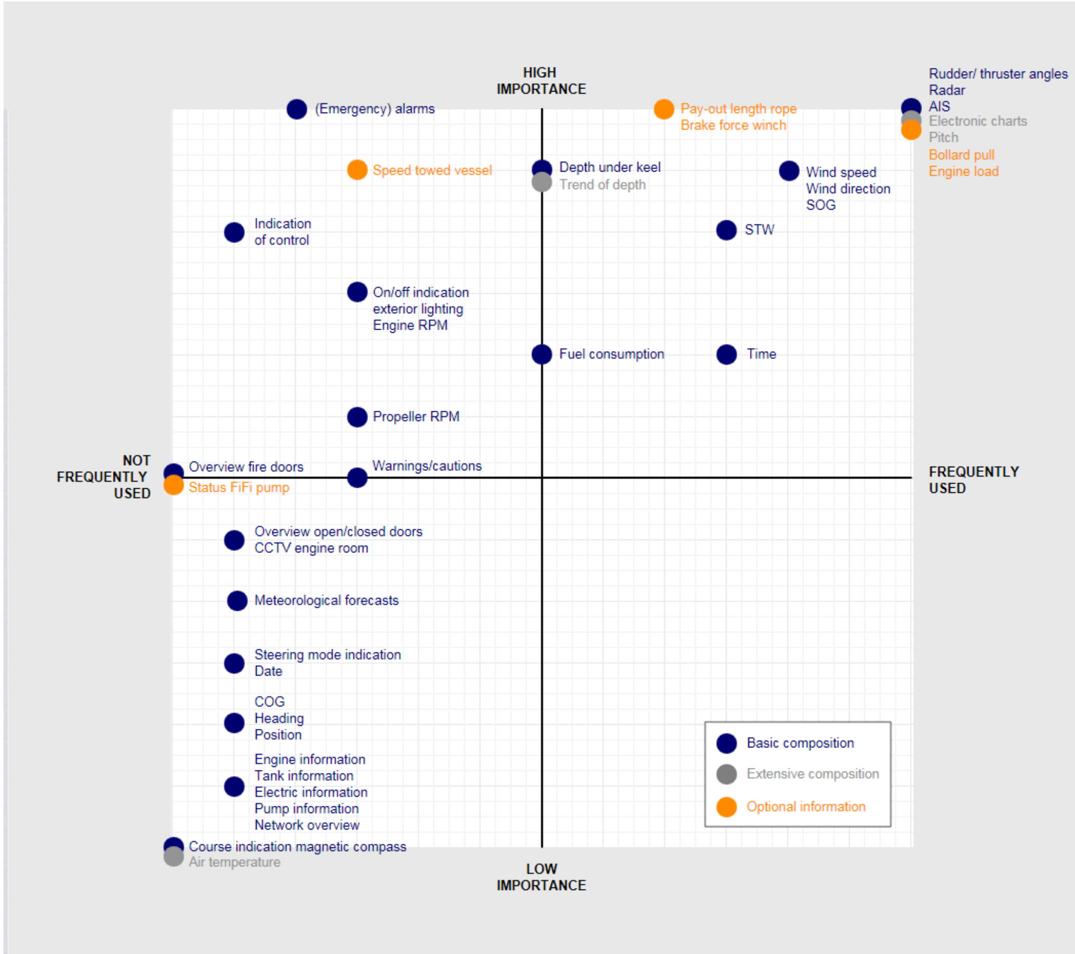

Figure 30: Priority matrix captain, category 1 vessel

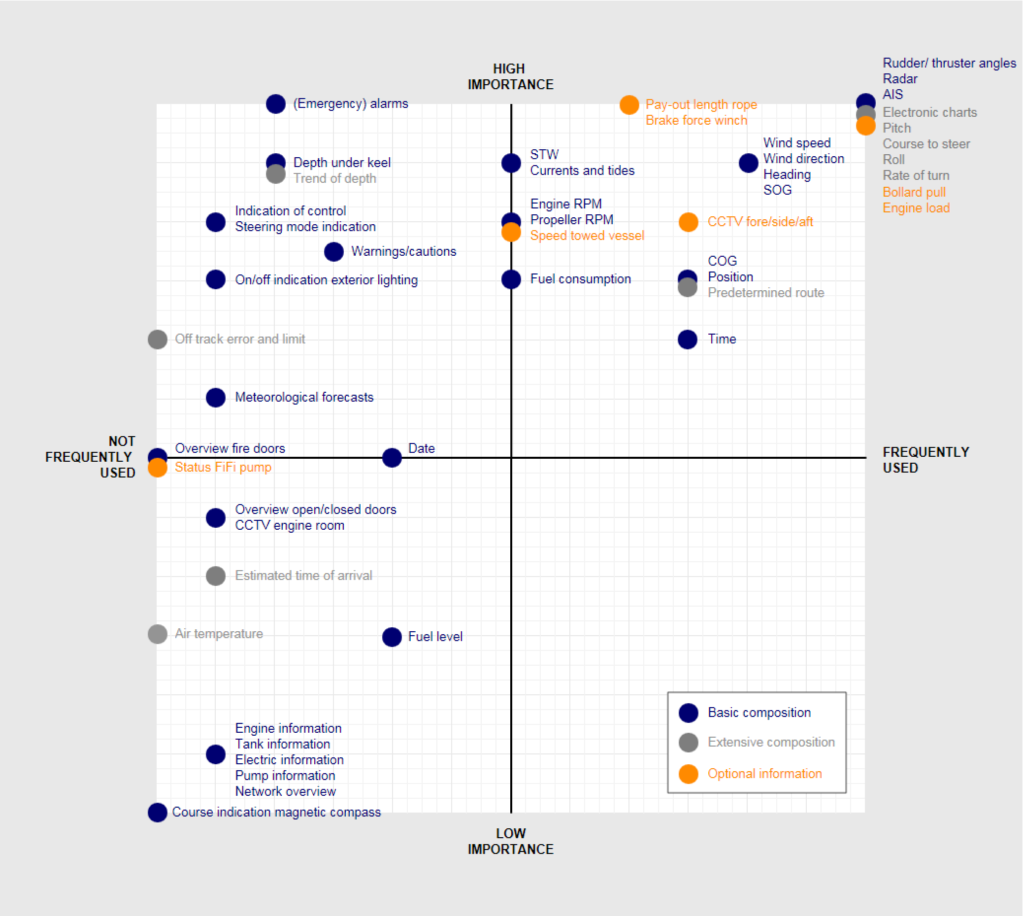

Figure 31: Priority matrix captain, category 2 vessel

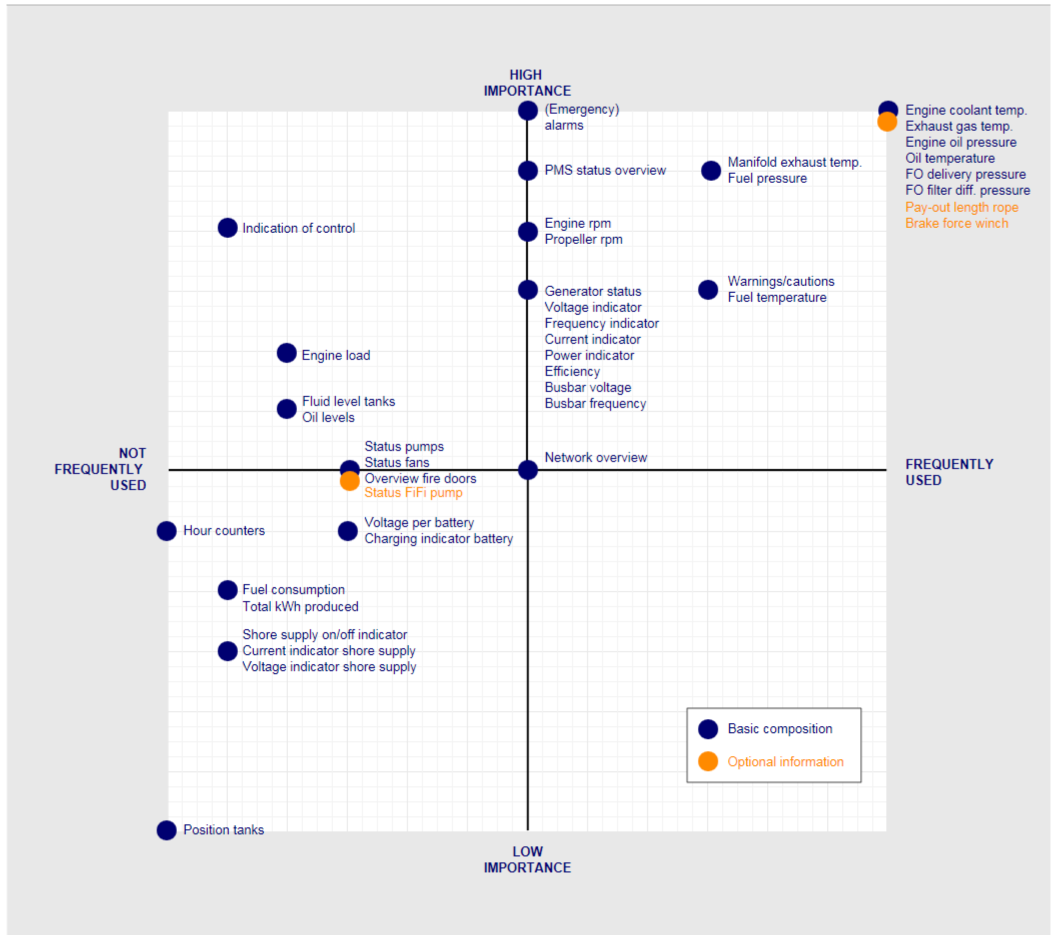

Figure 32: Priority matrix chief engineer

The reasoning behind the matrices and additional remarks about information importance are given in Appendix M: Results card sorting.
Overall it can be concluded that propulsion, maneuvering, and safety information is the most important information for a captain. In addition it can be stated that the status of the equipment, especially the status of the engines, is the most important information for an engineer.

How these results are translated into an actual information architecture is elaborated in the case study of chapter 8.

7.2 Conclusion user interface development

The card sorting sessions provided insight in the cognitive behavior of the operators and the importance and appropriateness of the different information items. This served as a basis for decisions according to the information architecture, functions that have to be included, and the graphical user interface.
Hereby the objective was to include a minimum amount of information in order to reduce the risk of cognitive overloading.
The user interface design philosophy is created independent of specific technologies as much as possible, to allow for the implementation of new technologies in the future. Hereby also the technical possibilities that became clear from chapter 4 are kept in mind. However display areas are taken into account since an increasing use of displays is expected. Therefore also a graphical user interface is provided.
Since the maritime industry is currently at a stage where automation is gaining more importance, attention is paid to the technical implementation of the automation system. Furthermore an option to automate the regulation of certain processes is included, however the choice whether to make use of this option is still up to the operator.

8. CASE STUDY

To give insight into the application of the design strategy and its tools, a case study for a specific vessel type is performed. This serves as a first validation of the proposed strategy and related results. It provides for example insight in whether the strategy provides the right support to come to a useful concept design, and whether the tools support the designer in making objective and thoughtful decisions.
This results in an interface design concept for a vessel type. The interaction with the first version of the concept design will be observed. Users and Damen employees will review and evaluate the results which will be used to confirm, refine, or remove design specifications. In the end this will lead to a set of recommendations for implementation of the newly designed concept. The final concept is presented in the Research synthesis.

A tug seems the most interesting vessel to include in the case study since the development of the entire wheelhouse is only performed in-house at the Tugs Product Group. This means that Damen has the responsibility for the tug wheelhouse design and the underlying development processes. This offers good conditions to make improvements and allows for faster implementation of those improvements. It also fits with the philosophy of the wheelhouse design strategy.
Moreover the tugs belong to the group of Damen vessels that are sold most, which increases the relevance to improve the wheelhouse design for those vessels.

In this section background information is given about Damen tugs, their way of operating, and user goals. This is illustrated by a tug specific use case. All these elements are also proposed by the strategy roadmap, and serve as important input for development of the tug alarm, monitoring, and control system concept.

8.1 Tugboat specific information

The current portfolio of Damen tugs is shown in figure 33. The vessels are outlined on basis of their speed of operation and the main area wherein the tugs are operating.

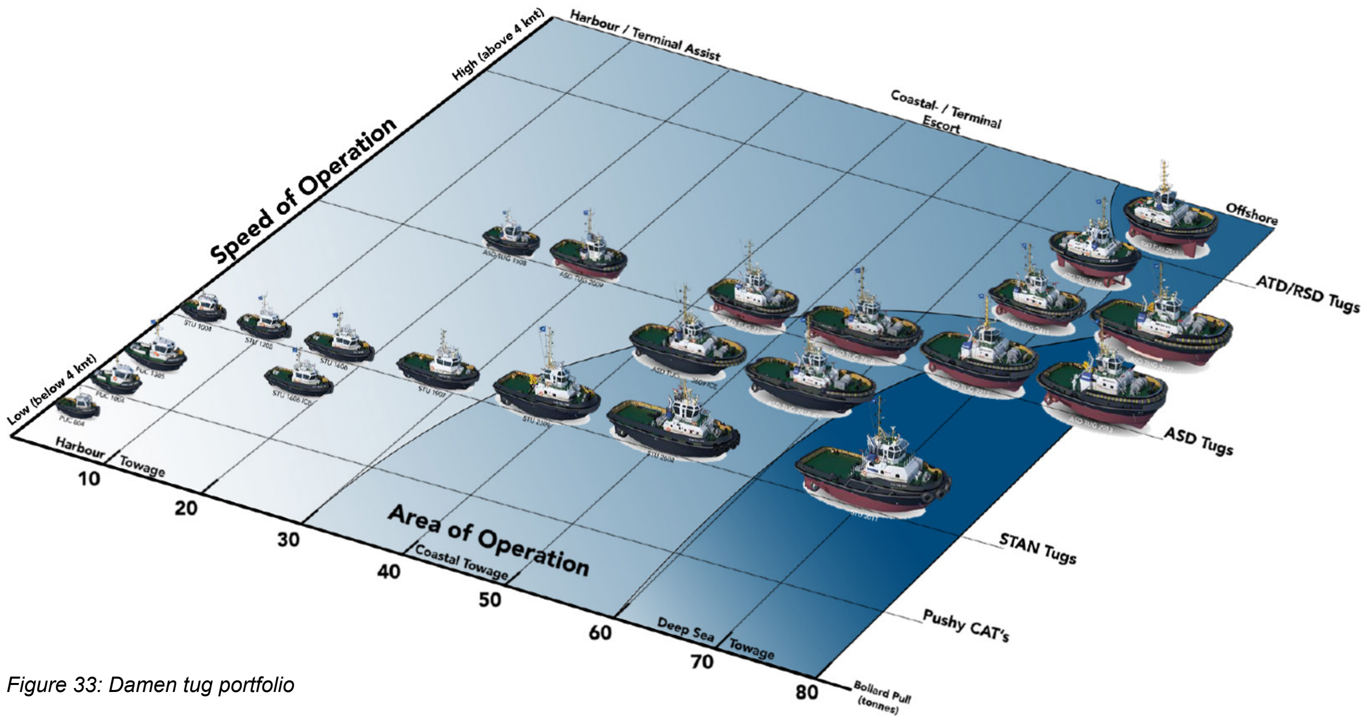

Figure 33: Damen tug portfolio

The differences between the types of Damen tugs are related to their application, and are expressed by their means of propulsion and hull shape, see also figure 34-37.

1. **Pushy Cat**: this tug is equipped with a classic fixed screw and a single plate rudder. Its main purpose is to perform push operations
2. **Standard (STAN) tug**: this tug is also equipped with a fixed screw and rudder combination, however it can be used for different operational purposes
3. **Azimuth Stern Drive (ASD) tug**: this tug is equipped with azimuth drive; a nozzle which incorporates a propeller that can rotate 360 degrees. This provides better maneuverability than the standard fixed propeller and rudder combination. Two propellers are positioned at the back of this vessel. The vessel delivers the best performance when sailing ahead. The consoles are positioned at the front of the wheelhouse.
4. **Azimuth Tractor Drive (ATD) tug**: This tug is also equipped with an azimuth system. Two propellers are positioned at the front of the vessel. The vessel delivers the best performance when sailing astern. The consoles are positioned at the back of the wheelhouse.
5. **Revers Stern Drive (RSD) tug**: This tug is also equipped with an azimuth system. Two propellers are positioned at the back of the vessel. Two 'twin-fin skegs' at the front of the vessel allow for the same performance when sailing ahead and astern. The consoles are positioned at the front of the wheelhouse.

The concept will be applied on an ASD tug, because this is currently the most sold tugboat; it is the most demanded type of tug by the market. Since the vessel layout and applications are closely related to the ATD and RSD tugs, the concept will also be useful for these type of tugs.

Figure 34: STAN tug

Figure 35: ASD tug

Figure 36: ATD tug

Figure 37: RSD tug

Trends

The tugboat market is influenced by several trends. This also requires the following changes in the design of the tugs itself:

1. Tugs have to become more powerful. On the one hand this is required because of commercial vessels that are getting bigger. On the other hand this is caused by the trend to use less tugs per pilot vessel in order to reduce expenses.
2. Tugs need to be designed in a way that they can be operated with less crew. This is caused by the trend to reduce the amount of crew members per vessel, in order to reduce expenses. Currently the Damen tugs are designed to operate with three crew members but the objective is to reduce this to two crew members.
3. Tugs have to become more user friendly in their operation and control since the operator gets a greater overall responsibility. This is caused by the two trends that are outlined above. Careful application of human factors has to support the operator.

8.1.1 User goals

The main goals of a tug captain are to:

- Assist other vessels in an efficient way
- Have good communication with its crew and the pilot
- Operate in a safe way, also for the other vessels involved
- Sail in a comfortable and pleasant way

The main goals of a chief engineer are to:

- Ensure that the tug can operate in the way as intended
- Keep the equipment in the best condition
- Operate the winch in a controlled and safe way
- Ensure overall safety on board of the tug

To achieve these goals it is important to gain the right information at the right time.

8.1.2 Use case

A use case specifies the interaction between users and systems by achieving goal(s). In this way a deeper understanding about the human-machine interaction in a specific context can be gained. A use case about a general towing procedure is outlined in figure 38.
More detailed information about the towing procedure and what kind of assistance can be given is outlined in Appendix N: Background information tugs.

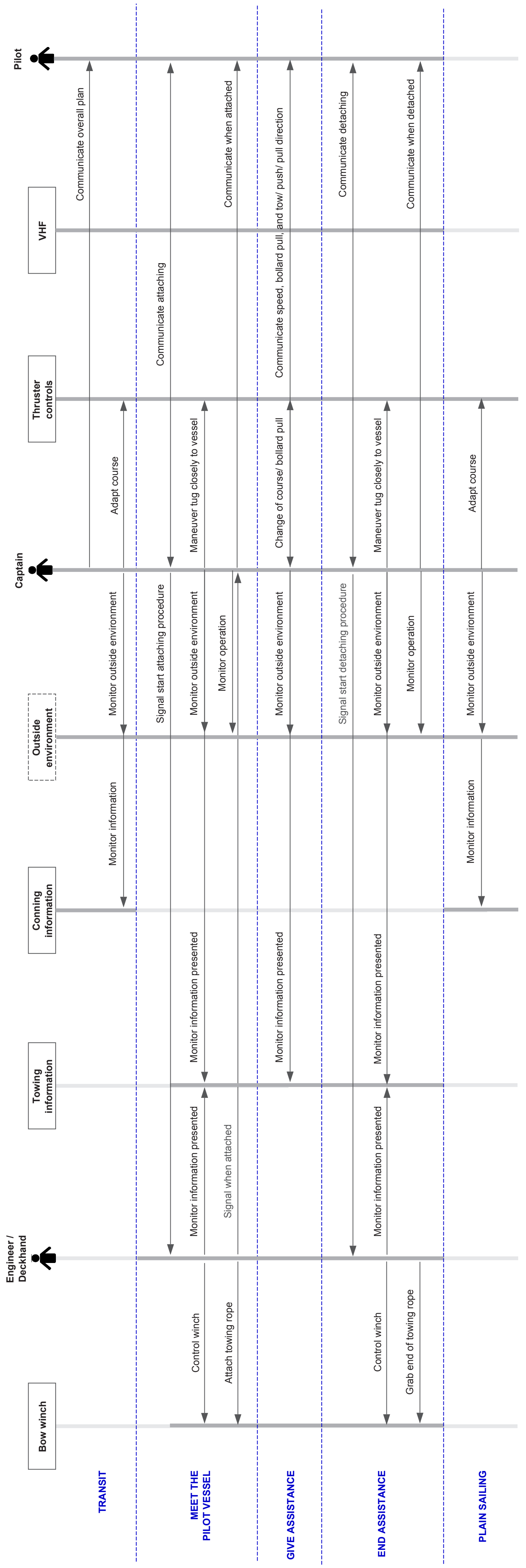

Figure 38: Use case towing operation

Towing information includes information like bollard pull, pay-out length of the towing rope, engine load, and brake force on the winch. See also the information architecture in the Research synthesis.

8.2 Concept evaluation

The alarm, monitoring and control system concept for an ASD tug is presented in the Research synthesis.
The first version of this newly proposed concept was evaluated, and an iteration was made as proposed by the strategy roadmap. The evaluation was performed to test its ease of use and to observe interaction between the user and the system. Hereby the main aim was to evaluate the information structure and presentation, and the design choices that were applied. This was done on basis of the feedback acquired.
The usability of the first version of this system concept was tested with different users by means of a Powerpoint prototype. The results of these evaluation sessions will be outlined in this section, even as the improvements that were made on basis of these evaluations.

During the tests a small part of the total wheelhouse was included since the focus was on the human-machine interaction on the bridge, specifically the interaction between the captain and the information that is offered. Influences from other components of the wheelhouse and the outside environment were taken into account where possible, though since the development of the user interface is in a conceptual stadium this had less priority. Furthermore engineers were not taken into account during the test sessions since their part of the system was not completely worked out. However external influences and engineers need to be taken into account in a later stadium, in order to get objective and complete results.

8.2.1 Test setup

It concerns a controlled study which means that participants were performing the test outside their normal working environment; a Damen meeting room. The setup is shown in figure 39.

Figure 39: Test setup

The test was performed with the use of an interactive PowerPoint prototype of the AMCS concept, which represents a part of the total AMCS and is a simplified version of the actual version.
Three captains and two Damen employees have participated, who differed in terms of age, education level, and experience with digital systems. The employees were included to gain more feedback since only a few captains were available. Both employees are closely involved with the development of the bridge and also have regular user contact.
The participants did perform different tasks with the system prototype while being observed. Hereby the time to perform the tasks and the errors made were listed. Afterwards a questionnaire was filled in and several open questions were answered by the participants. More information about the setup, tasks, and questions can be found in Appendix O: Usability testing.

8.2.2 Results

To determine the usability of the concept, first the meaning of the term ‘usability’ is analyzed. Hereafter a summary of the most important outcomes is given.

According to the International Organization for Standardization, usability is defined as the “Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” (International Organization for Standardization [ISO], 1998, p. 3). So the usability of the concept is dependent from the following criteria and the extent to which they are met (Stone, Jarrett, Woodroffe & Minocha, 2005):

- Effectiveness: the accuracy and completeness with which the goals are achieved
- Efficiency: the resources needed to achieve the goals in an accurate and complete way
- Satisfaction: the comfort and acceptability of the product as experienced by the users during use

From the user observations, the speed at which certain tasks are performed, the errors that are made, and the results of the post-test questionnaire, it becomes clear that the participants are positive about the general use of the interface, its appearance, and the positioning of the information on the mimics. Though, it seems that the structure, insight in the capabilities of the system, and the amount of feedback can be improved. So in case of effectiveness and efficiency there are some opportunities to improve. The most important results are listed below:

- More awareness has to be created about the user's current position within the system by providing feedback
- The need to show the available options that can be chosen from is emphasized, since these items were better understood. For example showing the menu keys as a default will contribute to a better understanding of the information that is shown.
- It is very important to choose the right icons, otherwise it can cause a lot of confusion. Evaluating them with the actual users is experienced as very useful.
- It might be useful to make a distinction between information that is needed during fastening of the tug and information that is needed during the actual towing operation. In this way the user can be more specifically supported during a towing operation.
- The information grouping provides a valuable basis for the new system and for its use
- The importance of the underlying information architecture is validated; at places where the structure was less clear it led to confusion of the user.
- Several design choices turned out to suit the user, for example to show the number of notifications under the icons on top. While others did clearly not, for example the choice to only show the menu keys by sliding over. Therefore it can be concluded that more support can be offered in making the right design choices.

The results of the questionnaire are shown in figure 40.
Overall it can be concluded that:

- A positive attitude is engendered in users by using the application, but its ease of use can be improved
- The usefulness of testing is emphasized; even with a simplified prototype within a controlled environment it provides a lot of useful insights and feedback
- Within the context of the case study the strategy has provided a good basis for a new concept design
- The process of making relevant design choices during the development process can be better supported

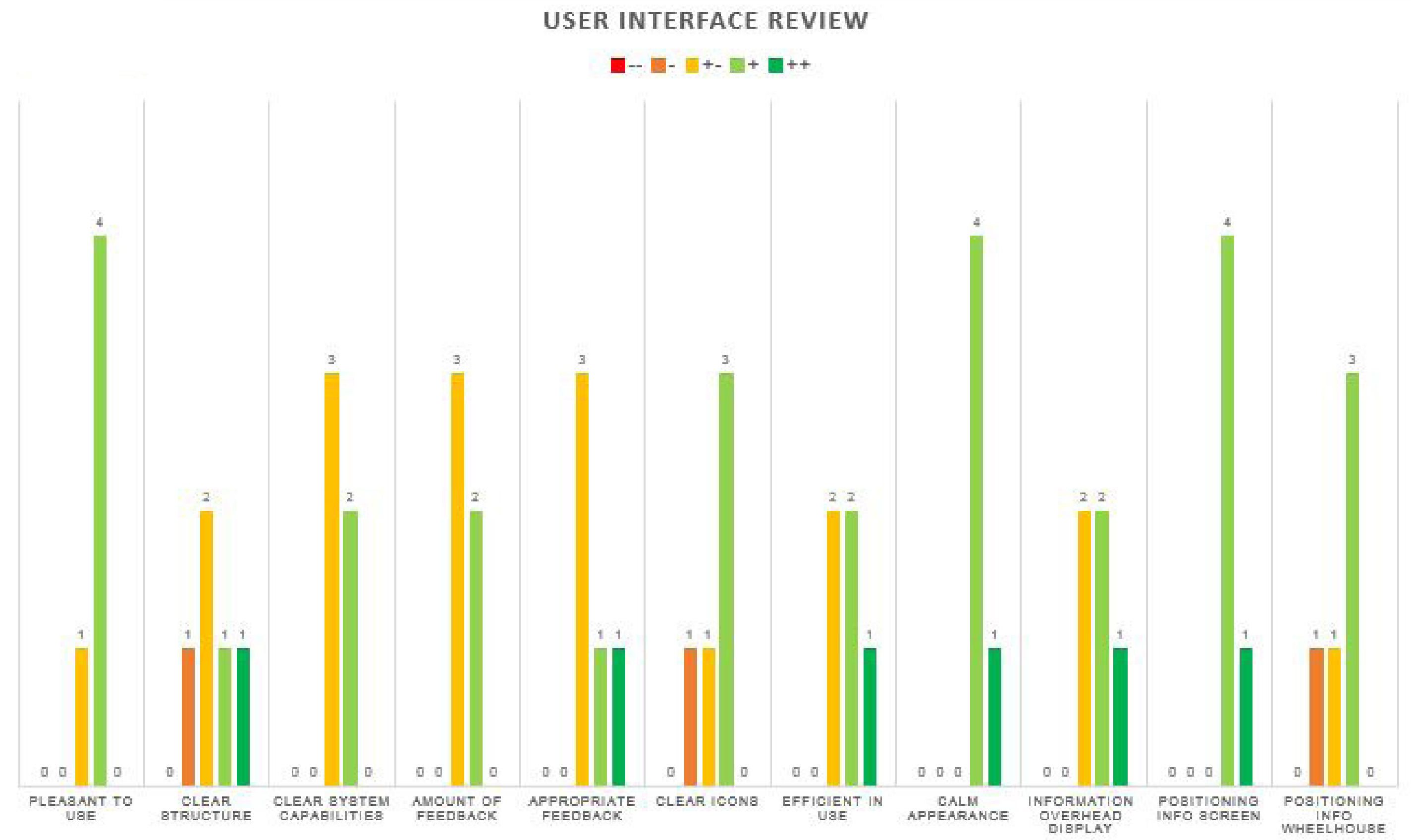

Figure 40: Results post-test questionnaire

8.2.3 Improvements

The following changes are applied as a result of the evaluation sessions, with the aim to improve the usability of the overall concept.

- The application and choice of icons that are applied within the graphical user interface are reconsidered and improved when needed. For example icons are left out by the (sub)menu keys because they do not lead to a better recognition of these items. The wind and navigation light icons are replaced by maritime versions.
- The positioning of the menu and submenu keys is improved by placing them on top of the screen instead of the bottom, in order to create a more clear, overall picture. Moreover the menu item that is selected is displayed larger than the others to emphasize its selection, and to make it better visible from larger distances.
- The distinction and meaning of the separate information items is emphasized by placing them all in separate areas including a textual description
- Little adjustments are made to the information architecture. For example the winch control functions are included, the Damen page is moved, and the control from the main deck is left out.
- The system requirements are updated so they can better support the decision making process. The requirements can be found in Appendix A of the Research Synthesis.
- In order to support general decision making during the development process, the most important reminders are summarized. Also a brief overview is provided of important aspects that have to be taken into account by designing a user interface. Both can be found in the Research synthesis.

The improvements have led to the final AMCS concept for an ASD tug, as outlined in the Research Synthesis. The compliance of this concept is checked with the requirements (as drafted in Appendix A of the Research synthesis). The concept meets the requirements that are applicable to the concept design. Though to be able to draw objective conclusions about the usability of the concept, it must be elaborated in its entirety. Furthermore is has be tested within an actual wheelhouse.

8.3 Conclusion case study

The type and amount of participants for the test sessions were not sufficient to draw conclusions with great certainty. However it did serve as a way to justify things that were expected. Moreover it gave valuable insights in aspects that were assessed differently. So it has contributed to improvement of the concept. It also gave insight in the underlying processes and how these can be better supported for the designer.

When the entire concept is worked out within its context, it will be possible to objectively evaluate its intuitiveness, and whether it increases the situational awareness and ergonomics for the user.
Though this research provides a good starting point for further testing and research, and has led to promising results so far.

Performing the case study also provided insight into the usefulness of the roadmap within this research. It can be concluded that the design process that is completed contributes to the concept design it has resulted in. The context and usability research helped to make the right assumptions during design. In general it can be stated that thorough research at the start provides a lot of useful insights about the product and its intended use, and will help to reduce the amount of iterations later in the process.
The case study also emphasizes the importance of performing user tests during the design process, since it shows to be a valuable way to validate assumptions that are made about the use of the relevant product. For example it was assumed that by hiding the menu options it would provide a calmer appearance and thus support the operator in performing its tasks. Though the test revealed that it led to an opposite effect; it worked confusing and did not contribute to the operator's task efficiency.
By applying the design principles it became clear that additional support might be useful in this process, since the principles can be applied in different ways. This deserves more attention, especially within an organization where knowledge about this topic is rarely available. Therefore extra attention is paid to this topic.
To give more insight in why it is useful to perform certain roadmap activities, an additional explanation of their goals might be helpful. These goals can for example be included in the online version of the roadmap, which can be shown by clicking on the relevant item.

CONCLUSION SPECIFICATION AND DESIGN

The Specification and Design phase resulted in a final system concept for an ASD tug, which serves as a solid base in developing a Damen wheelhouse standard. It also served as a first validation of the wheelhouse design strategy; several activities of the roadmap appeared to be useful in creating the interface concept.
The concept also gives insight in the relevance for Damen to incorporate human factors in wheelhouse design. However the concept need to be further elaborated, whereby all elements of the wheelhouse and means of interaction have to be taken into account. In that stadium new user evaluations within the actual context need to be performed, and objective conclusions about its usability and feasibility can be drawn.

The design strategy proposes more centralized wheelhouse development within Damen. This will require a change in the way how current business processes are performed. However it will support standardization and a single source of truth; aspects that Damen wants to improve. A greater knowledge base has to be created which should lead to objective decision making. Furthermore, continues insight in technological developments and the support of creativity will drive innovation. This will help to distinguish Damen from its competitors.

The strategy roadmap allows for good overview. By performing several processes in parallel it is easier to redirect certain processes if necessary. This also allows for adaptability to future changes, according to changing goals, functions, and responsibilities of the operator on the bridge.
To support the performance of the activities of the roadmap, a strong introduction and launch within Damen is needed. Hereby the relevance and importance (especially for the employees) have to be emphasized in a visual manner. It has to be indicated how certain changes might impact the work of the relevant employees and what the added value is for them. An added value can for example be that the wheel does not have to be re-invented for every project, or that a better understanding is achieved about why certain decisions are made. The introduction and first development of a Damen standard will take the most effort. Though when this basis is created it will become easier to iterate, improve, and maintain this competitive advantage.

PHASE III
EVALUATION

The aim of the Evaluation phase is to validate the results that are generated by the previous phases. The performed research approach and the research results are evaluated and discussed. This will reveal their strengths and weaknesses and will lead to several recommendations. These recommendations serve as valuable input for further development of the integrated wheelhouse design and for further research in this field.
In the end an overall conclusion is given in order to state if the main research aim is achieved.

9. DISCUSSION & RECOMMENDATIONS

The research approach, final concept, and the activities that are performed to come to this concept are evaluated. Hereafter the wheelhouse design strategy and its usefulness are outlined. On all topics recommendations are given, even according to future trends that are expected.

In general the research approach has served as a good basis for the research. To gain insight in the total context, bridges of different vessels were analyzed first. Analyzing different vessel types (instead of one) provided valuable input for developing a strategy that is applicable for different Product Groups.
When looking at the Foundation, it could have been useful to conclude this phase with a brainstorm session with Damen employees of different departments. Hereby the main results, usability issues, and first ideas could have been presented and discussed. For future projects this is recommended in order to provide insight in the needs, desires, possibilities, and constraints from Damen perspective in an early stadium. Moreover engineers could have been involved more intensively during the Foundation, since they also play an important role within the bridge environment.

The final alarm, monitoring, and control system concept provides several improvements with respect to the current bridge. Hereby it is kept in mind that the concept has to work intuitive for people with all kinds of technological knowledge levels.
It can be concluded that the concept has become a more incremental result rather than a radical solution. On the one hand this seems not as revolutionary as where Damen wants to be in the end, on the other hand the result serves as a solid base to move further in the right direction. Moreover the concept allows for fast implementation since it fits the current wheelhouse. And it is assumed that providing a new alarm, monitoring, and control system can already achieve large improvements for the user. The research also gives insight in the dependencies between different elements of the wheelhouse, which are mainly revealed during the Foundation phase.
The concept itself has a moment-specific screen lay-out; a distinction is made between sailing (to/ from the job) and the actual towing operation. To support the operator in specific situations a more detailed distinction in situations can be made, for example by providing situation specific information during attaching/ detaching of the tug, and during berthing of the vessel. Information that would be useful in these situations are a top view of the vessel and its tug(s), and the distance between the vessel and the shore. However to be able to show this kind of information, innovative technologies are required like sensor technologies, high definition cameras, and augmented reality. Since these technologies are not ready to be implemented in maritime applications yet (at acceptable costs and with a high reliability) this kind of information is not included in the concept. Though further development and testing of these technologies can lead to useful solutions that suit the marine environment. So the performance of extensive research in this field is recommended. However it should be kept in mind that even if a technology is ready, regulations of Classification can obstruct its implementation. But by demonstrating that a technology is of added value (for example in terms of safety), this can accelerate the process to change certain regulations and thus support implementation.

During concept development a lot of attention is paid to monitoring and control tasks and how these can be supported. However more attention has to be paid to voyage planning and reporting tasks, and how the crew can be better assisted in performing them. Especially since a solid planning appeared to contribute to a better situational awareness. This can for example be done by providing a checklist tool which reminds the crew of tasks that have to be performed prior to a voyage or operation, or by providing a system that allows for easy reporting.
The case study served as a valuable way to link my ideas to the actual practice. However during this study the performing of a link analysis could have provided more insight in prioritizing of the design principles, which is an essential aspect of the application of the principles.

By developing the strategy it is investigated how product feedback can be integrated in the development of new products. However the focus mainly stayed on how this feedback can support (objective) decision making. Hereby it was assumed that the feedback was already acquired and used. Though better support to acquire this feedback might be preferred, even as the actual managing of the integration of this feedback. Hereby it is key to provide an efficient communication tool which allows for centralized collection, and which contributes to an easy way to keep the feedback overview up to date. The opportunities for such a tool have to analyzed, for example within the new Damen Product Lifecycle Management (PLM) system that is currently introduced in the organization.
The introduction of the strategy and roadmap will bring along some changes in the current way of working. This might cause some resistance within the Damen organization. Hereby it is particularly important to clearly indicate how these changes impact the work of the relevant employees, and why this is for added value for them in the end.
By applying the design principles it is difficult to objectively assess if the design principles are met, since this differs per situation. This makes testing of the design essential, which has to be supported by user interviews and questionnaires. The assessment and translation of the principles into specific and measurable requirements might require experts in the field of (interaction) design.

During the usability tests of the final concept only a small part of the wheelhouse was included. In order to obtain objective and complete results, also tests have to be performed with the entire wheelhouse concept in its context. At first instance these can be performed within a simulated wheelhouse environment, whereafter tests can be performed on a real vessel. In this way also the influence on the operator can be analyzed, for example how it affects its workload, situational awareness, etc. Also the influence of elements from the outside environment (waves, sunlight, operational conditions) on the usability can be analyzed in this way.
For the user evaluation tests no specific tugboat captains were available. During the tests it was also noticed that they had less tug specific knowledge, which made their feedback on certain topics less valuable. So for the final user tests it is crucial to let captains participate that sail on the type of vessel the concept is developed for. This means that the travel schedule of the relevant captains has to be taken into account by scheduling these tests. If other crew serves as a frequent user of (parts of) the wheelhouse they also need to be taken into account during the tests, for example chief engineers.
Furthermore it will be really useful to test the concept with foreign users, since their mental model and knowledge level can differ to a large extent from Dutch or European users. This is also important since Damen vessels are sold globally and used around the world. Also a minimum amount of 5 actual users is recommended.

A lot of choices made during the development of the strategy and concept are based on information according to tugboats and their users. In order to better suit other Damen vessels it might be useful to gain more input from other Damen vessels or Product Groups. During this research these resources were not always available within the available time.

The research scope includes system complexity and interface design. To come to a complete and integrated wheelhouse concept, also other aspects that influence the user experience and vessel operation need to be taken into account. This relates for example to the materials applied within the wheelhouse, and the design, appearance, positioning, and reachability of the different components. Hereby relevant elements to review are:

- The console design, to come to a design that requires less space and that has a 'lighter' appearance. A separate processor room for the computers can be considered, which should provide more space within the wheelhouse.
- The top plate of the console and its production, to acquire a console wherein all components can be flush mounted in order to achieve an equal surface. Hereby the feasibility of a (simplified version of a) foil bridge panel can be investigated, as currently applied on yachts.
- The overhead positioning of components; this area provides a lot of opportunities to arrange certain components. This may contribute to better interaction and a calmer overall appearance.
- Damen design standards which are applied on all Damen vessels, this contributes to the overall consistency
- Iconic style elements of Damen, to create a Damen identity within the overall wheelhouse

Furthermore it has to be investigated to which level it is possible to integrate the different equipment items (from different suppliers). Hereby some small improvements are already possible. For example instead of two separate searchlight panels (fore and aft), one search light panel can be provided whereby fore/ aft can be selected.
When looking at the future a completely integrated ship bridge system is expected, whereby all systems are accessible by a single software system with a single input device.

More research can be performed to analyze how the benefits of the principle of modularity can be maximized. For example it can be investigated whether it would be feasible to produce all Damen wheelhouses with 50% of the same components. Extensive research will be needed, also to the integration into the current business processes, but it might provide a good solution to achieve a more efficient production.

Aspects that will gain more importance for vessels in the future are condition based maintenance and remote monitoring. By accurate monitoring of the vessels' state and its systems maintenance can be performed more efficient. This can be done by means of remote monitoring with on board cameras and sensors. The first tests with remote monitoring are already performed within Damen. Though to be able to respond to these changes and to be ahead of it, more extensive research in this field is needed.
However by applying more automation it has to be kept in mind that the need for the user has to be leading!
In the end technological changes may even lead to remote support and operation of vessels. Though since 155 countries have to agree with changes in the current international maritime legislation (as regulated by the International Maritime Organization) this may take a while.

10. CONCLUSION

In this section it will be assessed if the main research goal is achieved, by looking at the research results and choices made during the overall process.

Taking the entire wheelhouse as starting point for the design strategy is experienced as useful in order to see the bigger picture, which is also important during wheelhouse development. By combining market pull and technology push strategies it is aspired to both fit user needs and technological boundaries, and to trigger innovative solutions. This is in line with Damen's objectives.
Through completing several roadmap activities it can be concluded that these activities serve as useful input in developing the wheelhouse concept. Though the functionality and usability of the total roadmap has to be proven in practice within the organization. However the strategy will require changes in performing wheelhouse development in order to achieve more efficient development, and to come to a solution that is efficient, effective, and satisfactory in its use. For example certain processes have to be given more priority, like the performance of an extensive user study, and the integration of user feedback.

The research is focused on information supply, structure, and presentation, as also preferred by Damen. This has resulted in a concept that contributes to a reduction of the cognitive overload of the user, which is a major player in causing human errors on the bridge. However the reach and arrangement of components also appeared to have a large influence on the usability of the wheelhouse environment. Since the research does not fully cover this aspect it should be given priority when further elaborating the concept. Hereby also the design philosophy should take into account the reach and arrangement of components in more detail, since the philosophy currently mainly applies to the information provision within the wheelhouse.

The design principles provide insight in the aspects that have to be taken into account during (interface) design. When applied in a centralized way, it is assumed that they will contribute to more consistency in design. However their application can be performed in different ways, which makes it difficult to assess whether they are met in the right way. Situation specific priorities of the principles have to be defined, though this might require additional experts since this knowledge is currently not widely available within the organization.

The concept of the alarm, monitoring, and control system serves as a useful starting point for improvement of the wheelhouse. The calm appearance of the interface provides overview, which helps to achieve more efficient interaction and supports looking outside. Integration of different information sources is applied, however integration has to be performed on a higher level when a total wheelhouse redesign is established.
On basis of the user evaluation sessions it is assumed that the concept contributes to the improvement of the interaction with the AMCS. However since the AMCS is only one part of the wheelhouse, no objective conclusions can be drawn about the usability of the concept within its actual context (yet).
More research is needed in the context of real (or simulated) operations whereby the system is tested in the field. In this way also objective conclusions can be drawn about the influence the concept has on the operator's situational awareness.
Though the entire wheelhouse concept needs to be elaborated first. So for example full integration of different components and their positioning need to be taken into account. Furthermore the development and implementation of the concept will require a new graphical editor.

A tugboat serves as a suitable vessel to start improving the wheelhouse, since it is a relatively small and less complex vessel. It also provides good conditions to perform tests and to optimize the design. Hereafter the concept can be elaborated for vessels from other Product Groups.
The case study also served as a way to emphasize the relevance and importance (within Damen) of a more integrated and user focused wheelhouse.

Overall it can be stated that the strategy and concept provide a promising pathway for better integrated wheelhouses in order to increase the operational performance. The strategy is also in line with long-term strategic goals of Damen. Moreover the concept can help to reduce the problems as outlined in the introduction of this thesis.
A lot of further research, testing, and development will be needed to redesign the entire wheelhouse environment. However the strategy roadmap can play an important role in supporting these processes.

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APPENDICES

APPENDIX A: BRIDGE SYSTEMS

An overview and background information is given of the most important systems of the bridge environment.

1. Navigation and maneuvering

Information about the position of the vessel, its surroundings, and other vessels is provided by different equipment and systems that support navigation, surveillance, and maneuvering functions.

1.1 Radio Detection and Ranging system

The Radio Detection and Ranging (Radar) system detects and visualizes surrounding objects and the environment by means of radio waves (Louwerse, van Roeden, Haverkamp, & den Hollander, n.d.).
The system is able to show (Olsson & Jansson, 2006):

- A predetermined route with waypoints of the own vessel
- Surrounding ships and their routes
- Warnings on collisions

Two different radar systems can be used: an S-band radar that operates on a frequency of 3GHz, and an X-band radar that operates on a frequency of 9GHz. The S-band is used for less detailed imaging and has a large detection range, while the X-band is used for more detailed imaging and has a smaller detection range. Besides, the S-band radar is more stable in rough weather conditions so the image will be less influenced by rain and snow (Louwerse et al, n.d.).

1.2 Automatic Radar Plotting Aid system

A separate or integrated Automatic Radar Plotting Aid (ARPA) is used to evaluate and asses collision situations. Since the ARPA can determine the course, speed, and closest point of approach (CPA) of tracked objects (Louwerse et al, n.d.).

1.3 Global Positioning System

A Global Positioning System (GPS) provides position information of a vessel by the use of satellites and their signals. On basis hereof also the ground speed and the course over ground can be derived. To increase the accuracy of the position reference, also a ground based differential signal (DGPS) can be used (Louwerse et al, n.d.).

1.4 Automatic Identification System

An Automatic Identification System (AIS) automatically identifies and locates other vessels by means of transponders. Every vessel transmits information like their unique identity, position, speed, and course. The information is regularly updated and can be displayed (ShipInsight, 2014).
Via the AIS also written messages between ships can be exchanged.

1.5 Autopilot system

Automatic steering controls, like the autopilot system, automatically control the position and heading of the vessel. This can be based on the given waypoints of the radar. The system controls and keeps track of a vessel's heading, track, route, and speed (Louwerse et al, n.d.).

1.6 Dynamic positioning system

A dynamic positioning (DP) system allows a vessel to maintain a certain position and course. The system measures the forces of the wind, waves, and current. On basis thereof the force that have to be generated by the propulsion system is measured and controlled, in order to stay on its desired position (MarineInsight, 2016).

1.7 Compasses

A traditional magnetic compass determines a ships' direction related to the (magnetic) north.
A gyrocompass serves as heading indicator and is directed to the true north.

2. Monitoring

To keep track of different processes several aspects are monitored, like the state of the machinery, the vessel's speed, and its position. Several systems that are regularly applied are outlined below.
The conning display shows all (monitoring) information regarding steering, the vessel's motions and the technical systems.

2.1 Speedlog

A speedlog measures a vessels' speed through water.

2.2 Echo sounder

An echo sounder system measures the water level below the keel. The system sends and receives low frequency radio waves and on basis thereof the depth below the keel can be determined (Louwerse et al, n.d.).

2.3 Sound Navigation and Ranging system

A Sound Navigation and Ranging (SONAR) system maps the underwater environments by means of propagation of sound (Louwerse et al, n.d.).

3. Planning

Marine charts, both on paper and digital, are used to plan and display the vessel's route.
Electronic chart systems like the Electronical Chart Display and Information System (ECDIS) can also continuously monitor the position of the vessel. Electronic charts are able to show (Olsson & Jansson, 2006):

- Information and warnings related to land, objects, paths, and buoys
- Vessel heading
- Vessel speed over water and ground
- A predetermined route and its waypoints

4. Communication

4.1 Very High Frequency radiotelephone

A marine Very High Frequency (VHF) radiotelephone is a communication system that works via radio wave signals. It is used for communication between different vessels or between a vessel and the shore. Different frequencies or channels can be used (Louwerse et al, n.d.).

4.2 Intercommunication device

An Intercommunication device (Intercom) is a communication system that is used for internal communication on a vessel, for example between the engine room and the bridge.

4.3 Single Side Band radio

A Single Side Band (SSB) radio is a marine radio communication system that provides two-way communication between vessels (mutually) and the shore

4.4 Engine Order Telegraph

The Engine Order Telegraph (EOT) is a means to communicate engine power orders (in two ways) between the operator on the bridge and the chief engineer at the engine room.

4.5 Phone

A (mobile) phone is used for external communication.

4.6 Satellite communication

Satellite communication allows for transmitting data between vessels, and between vessels and the shore.

4.7 Sound powered telephone

The sound powered telephone is used for internal communication in case of an emergency, since this telephone requires no external power.

4.8 Voice pipe

The voice pipe is used for internal communication between the wheelhouse and the steering gear compartment in case of an emergency. The pipe is widely replaced by a sound powered telephone, however it is still mandatory for Italian vessels.

5. Safety

To ensure a safe operation there are several backup systems included in case one of them fails. For several systems or equipment this redundancy is even mandatory, as dictated by Classification.
An integrated alarm system has to aware the operator of failures. Furthermore several systems are needed to ensure safe operations. A few of them are outlined below.

5.1 Bridge Navigational Watch Alarm System

The Bridge Navigational Watch Alarm System (BNWAS) monitors the activity of the operator on the bridge. Regular instructions are given and if they are not acknowledged by the operator a sound alarm will be initiated.

5.2 Navigational Telex

Navigational Telex (NAVTEX) is a system that provides navigational and meteorological warnings and forecasts. A NAVTEX is usually a device with a small display to show broadcast messages, as well as to communicate urgent marine safety information. The updated information is automatically received (ShipInsight, 2014).

5.3 Global Maritime Distress and Safety System

The Global Maritime Distress and Safety System (GMDSS) is a set of international regulations with the aim to increase overall maritime safety. Requirements on equipment are stated so the system actually consists of several individual radio systems, which allows for rapidly sending and receiving alerts and messages in case of distress situations (ShipInsight, 2014).

APPENDIX B: REACH ENVELOPE

The functions that are frequently used should be placed close to the operator. The reachability of the input devices in relation to the seated position of the operator is shown in figure 41. Hereby a reference point is taken of 250 mm above the seat. The maximum distance from the working position for placing input devices is 1000 mm (within reach area), and 800 mm for frequently used input devices (within easy reach area) (Det Norske Veritas [DNV], 2011).

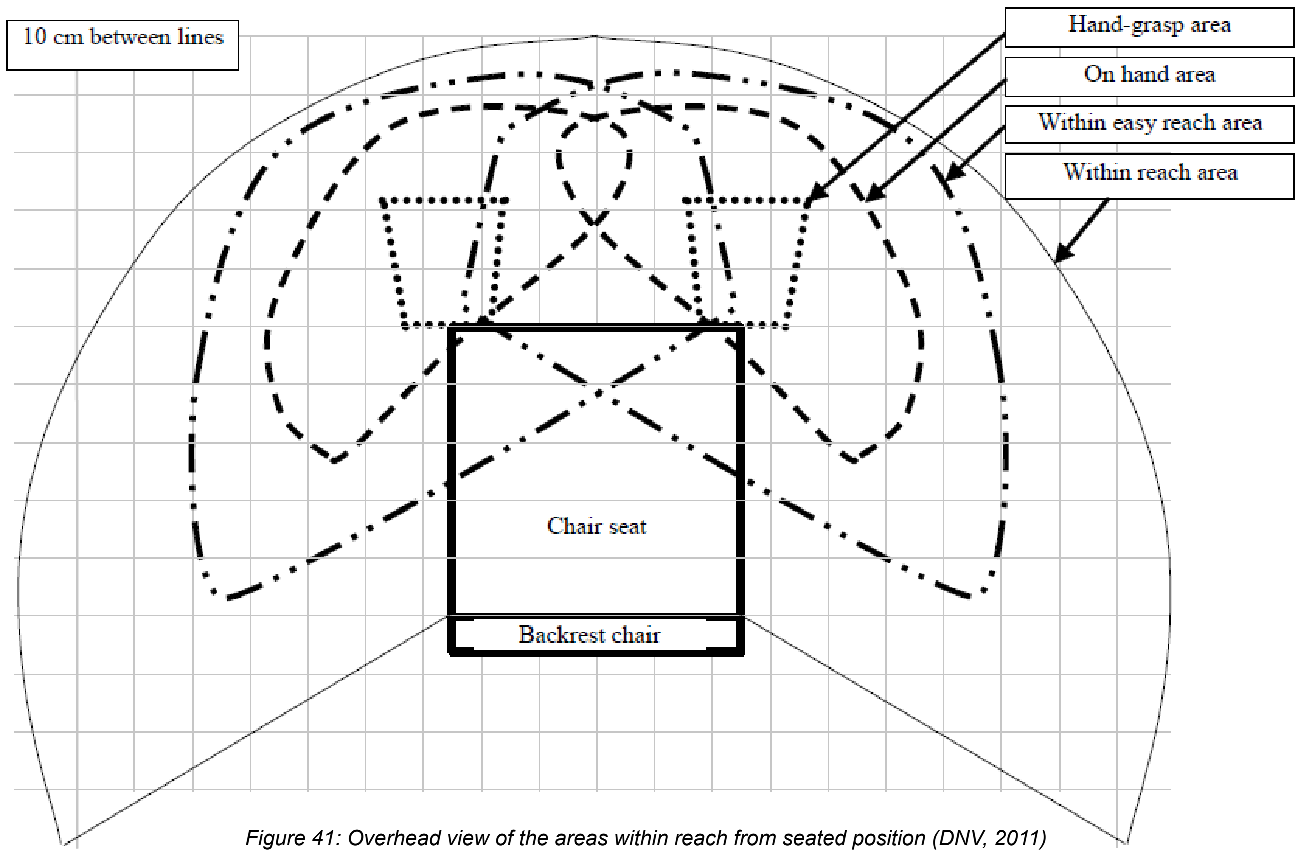


Figure 41: Overhead view of the areas within reach from seated position (DNV, 2011)

The reachability of the input devices in relation to the standing position of the operator is shown in figure 42. The maximum distance from the working position for placing input devices is 800 mm in forward direction, and 1400 mm in sideward direction (DNV GL, 2017).

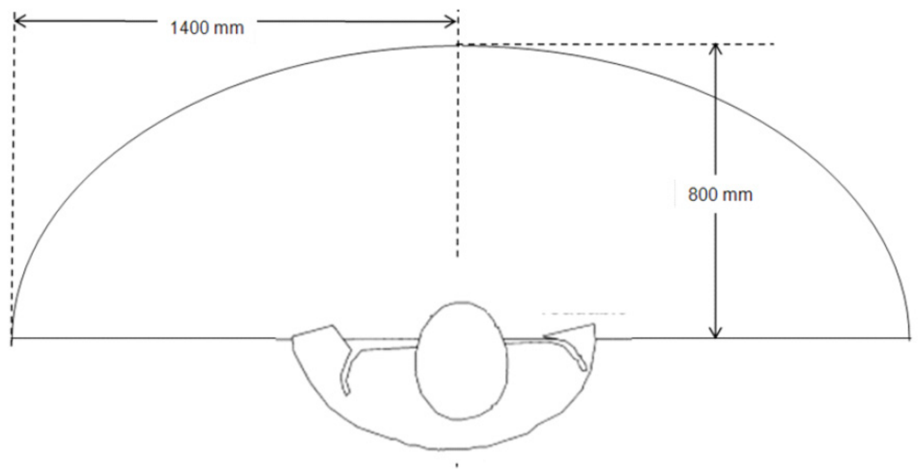


Figure 42: Overhead view of the areas within reach from standing position (DNV GL, 2017)

APPENDIX C: RULES AND REGULATIONS CLASSIFICATION

A short summary is given of rules and regulations that apply for the bridge environment, as stated by Lloyd's Register (2016).

Bridge arrangement

- The conning position is placed close to the forward central window
- The main steering position is placed on the ship's centerline
- Sufficient handrails or equivalent are included at the bridge to ensure safe operation in bad weather
- The navigating functionalities are also accessible from other workstations than the navigation workstation
- A clear passage of minimal 700mm is provided between separate adjacent workstations
- The bridge is free of sharp edges or protuberances
- Seating options (with securing) is provided on the bridge

Safety

- Alarm management is included
- Alarms related to navigation equipment need to be both audible and visual
- Acknowledgement of an alarm need to be expressed by manual controls
- Each part of an integrated bridge system can operate and function independent of each other, in order not to affect other parts of the system in case of failures (except those that are directly related to this system)
- Redundancy of interfaces ensures that all functions of the integrated bridge system remain accessible when an operator display fails
- Unacknowledged alarms are shown with flashing text or a flashing marker
- Acknowledged alarms are shown by illuminated text or an illuminated marker
- The centralized alarm system can show at least 20 items simultaneously
- All audible signals can be temporarily silenced by one action
- It is possible to immediately restore manual control
- Alarms and warnings are displayed on the conning display without masking, obscuring, or degrading other essential information.

Vision

- The effects of glare and reflections should be minimized (consoles, chart tables etc). Obscuration of information on visual displays is prevented.
- Lighting ensures that the crew can perform all bridge tasks during day and night. This also includes illumination of instruments and controls. Lighting is adjustable in case of brightness and direction
- During ship navigation at night, lighting of equipment may not impair night vision. Therefore red lighting or the like is provided
- A view of 360 degrees around the vessel is provided from the bridge, when moving around
- The maximum height of the consoles is 1350 mm and does not interfere with the field of vision

Line of sight

- The view of the sea surface from the conning position and the navigation workstation is not to be obscured by more than two ship lengths, or 500 m, whichever is less, forward of the bow to 10° on either side, irrespective of the ship's draught, trim and deck cargo (Lloyd's Register, 2016, p.1544). See figure 43.

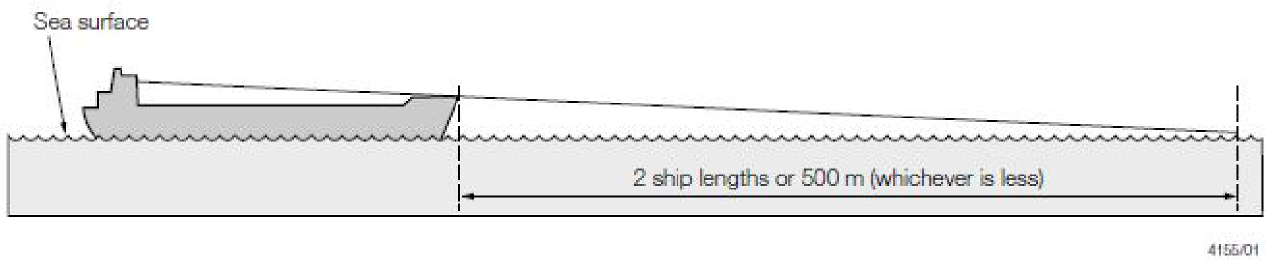


Figure 43: View on sea surface from the main steering position (Lloyd's Register, 2016, p.1544)

- The horizontal field of vision from the conning position and the navigation workstation is to extend over an arc from more than 22,5° abaft the beam on one side, through forward, to more than 22,5° abaft the beam on the other side (Lloyd's Register, 2016, p.1544). See figure 44.

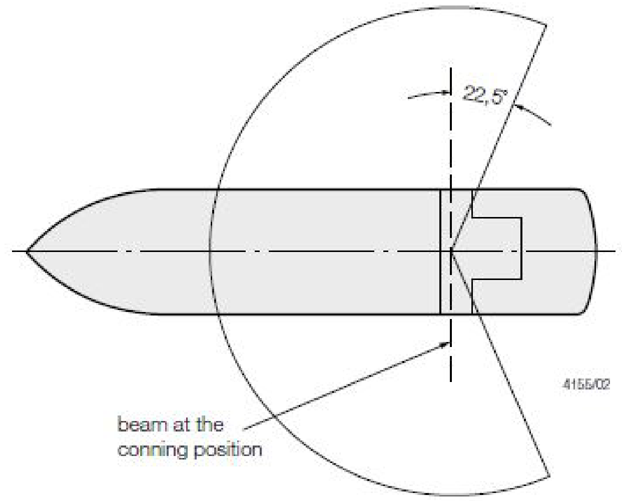


Figure 44: Horizontal field of view from the main steering position (Lloyd's Register, 2016, p.1544)

- From the main steering position, the field of vision is to extend over an arc from dead ahead to at least 60° on each side (Lloyd's Register, 2016, p.1544). See figure 45.

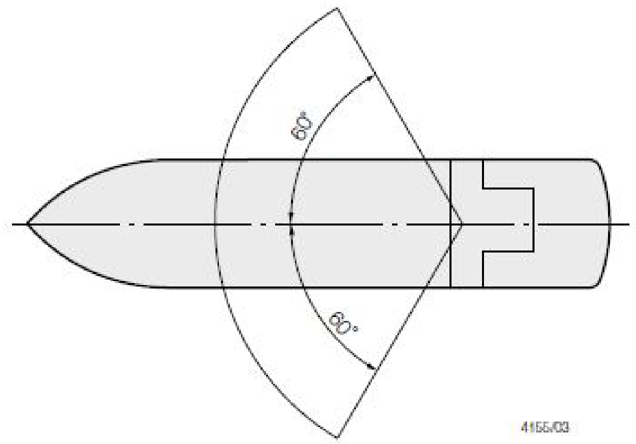


Figure 45: Field of view from the main steering position (Lloyd's Register, 2016, p.1544)

- From each bridge wing, the field of vision is to extend over an arc from at least 45° on the opposite bow through dead ahead and then aft to 180° from dead ahead (Lloyd's Register, 2016, p.1545). See figure 46.

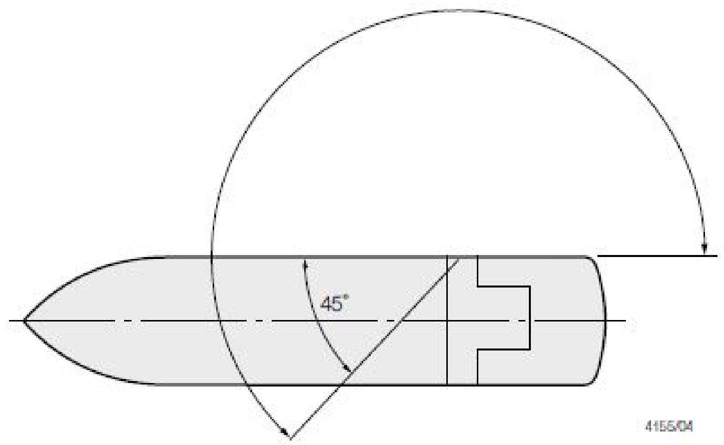


Figure 46: Field of view from starboard bridge wing (Lloyd's Register, 2016, p.1544)

- From workstations for functions other than navigation, the field of vision is to enable an effective lookout to be maintained and, in this respect, is to extend at least over an arc from 90° on the port bow, through for ward, to 22,5° abaft the beam on the starboard side (Lloyd's Register, 2016, p.1545). See figure 47.

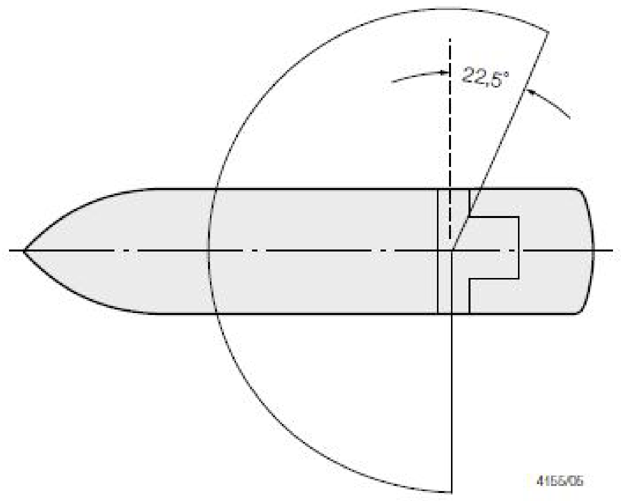


Figure 47: Field of view from remaining bridge positions (Lloyd's Register, 2016, p.1544)

APPENDIX D: TASK OVERVIEW

Table 2 shows the most common tasks that are performed within the wheelhouse. These tasks are drafted on basis of the results of user observations, interviews, the questionnaire for captains, and literature of the American Bureau of Shipping (2000, 2003) and Lloyd's Register (2016). Note that not all tasks will be performed during every operation or journey.

All tasks are divided over three categories: strategic (S), monitor (M), and control (C) tasks. Strategic tasks are those related to planning and those that anticipate on (possible) future situations. Monitor tasks relate to observation of systems, vessel behavior, and the outside environment. Control tasks include the operation of input devices like joysticks, buttons etc.
The importance and frequency of the tasks are defined on a scale from 1 to 3, whereby 3 is respectively the most important. This results in the priority of the task, expressed in 'high', 'medium', or 'low'.

Function	Task	Category	Importance	Frequency	Priority
Docking	Giving instructions, performing and controlling change of course	S/M/C	3	2	High
	Giving instructions, performing and controlling change of speed	S/M/C	3	2	High
	Giving instructions, performing and controlling change of rudder/thruster position	S/M/C	3	2	High
	Handling communication with other vessels (if applicable)	S	3	2	High
	Watching water surface along vessel's side	M	3	2	High
	Releasing signals	C	2	1	Low
Route planning	Examine and update charts and other relevant documentation	S	2	2	Medium
	Plan a voyage as a series of waypoints/ courses	S	3	3	High
	Calculate estimated time of arrival (at various points on the voyage)	S	2	3	High
	Plot (draw/ mark) the ship's position	S	2	3	High
	Capture optimum conditions (course, speed, weather conditions, current, tides etc.)	S	2	3	High
Navigation & Maneuvering	Check own course and speed	M	2	3	High
	Adjust own course and speed	C	2	3	High
	Check own position	M	2	3	High
	Monitor route/track	M	2	3	High
	Monitor propeller revolutions and rudder/ thruster angle	M	3	3	High
	Monitor water depth	M	2	2	Medium
	Monitor wind speed and direction	M	1	2	Low
	Interpret signals and lights of other vessels	M	1	2	Low
	Observe the sea for vessels, land, objects etc.	M	3	2	High
	Calculate closest point of approach (if applicable)	S	2	2	Medium
	Send sound signals	C	1	1	Low
	Decide on collision avoidance actions	S	3	2	High
Manual steering	Steering vessel according to rudder/ thruster angle information	C	2	3	High
	Steering vessel according to course instruction	C	3	3	High
	Steering vessel according to landmarks/ sea marks	C	3	1	Medium
Monitoring & Safety	Perception of alarms	M	3	3	High
	Acknowledge alarms	C	2	3	High
	Decide on actions alarm	S	3	3	High
	Observation of weather conditions	M	1	2	Low
Communication	Report weather observations	S	2	1	Low
	Report oceanographic reporting	S	2	1	Low
	Log keeping; note important events in the field of management, operation, and navigation	S	1	1	Low
	Communication with pilots, dock/harbor masters for port entry or leave	S	3	1	Medium
	Handling internal communication on board	S	3	2	High
	Handling communication vessel - vessel	S	3	1	Medium
	Handling communication vessel - shore	S	3	1	Medium
Miscellaneous	Fire control	C	3	1	Medium
	Flooding control	C	3	1	Medium
	Housekeeping bridge	M	1	3	Medium
	Structural maintenance	S	2	2	Medium
	Start/ stop engines	C	1	1	Low
	Control wheelhouse temperature	C	1	1	Low
	Control window wipers	C	2	2	Medium
	Control lights	C	2	1	Low

Table 2: Task overview

APPENDIX E: FIELD STUDY

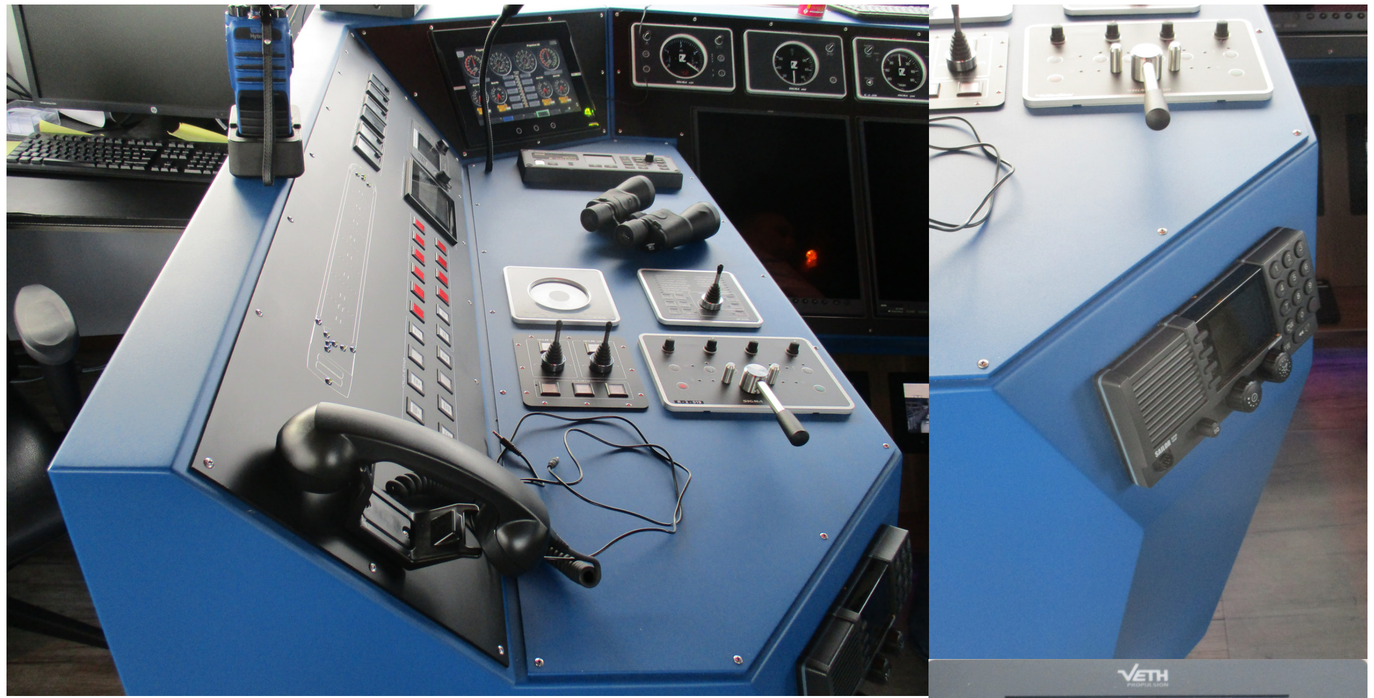
The bridges of different vessels are visited and their use is observed during several sailing operations. An overview of the related findings is presented below.

Visit bridges

Different vessels where visited to gain a general understanding of the bridge environment, its systems and components, and the differences between bridges on different vessels. This also served as a preparation for the actual observation during sailing. A Stan Patrol Vessel (SPV) 5009, Fast Crew Supplier (FCS) 2610, Inland Waterway Vessel Eco Liner 1145, and Azimuth Stern Drive (ASD) Tugs 2810 and 2609 ICE were visited. A visual overview is given below. The main observed usability issues are included in the usability issue overview of Appendix G.




Bridge Stan Patrol Vessel 5009



Bridge Eco Liner 1145


Bridge Fast Crew Supplier 2610

Bridge ASD Tug 2810

Observations

The results of the user observations during sailing are presented below. Background information is given to provide insight in the specific use situation. Captain comments describe the needs and desires of the captain. Moreover pictures are shown to support the textual description.

Observation Fast and Furious 12-09-2016

Fast yacht support (FYS) 5009

The first user observation study was performed on the Fast & Furious, a 55-metre Yacht Support 5009 vessel. During the sail also a dive hub, two ribs, and a container with dive equipment were on board.
The observation was performed during the first real sail from Gorinchem to Vlissingen. Observations were made during the entire sail of 10 hours, which included berthing/ unberthing, maneuvering, speed tests, passing bridges, and going through the lock.
The crew consists of the captain, chief mate (helmsman), chief engineer, field service engineer, cook/ deckhand and another deckhand.
The design and building of the bridge were outsourced to Alphatron.

Background information

- The main displays do not have touch screen but a separate dashboard panel with separate controls
- Electronic charts are not available
- In the middle part of the bridge the communication dashboard is placed, because it has less priority. These displays devices have touch screen
- From left to right, screen 1 – 5.
- Screen 1: Dynamic positioning (DP) system
- Screen 2: Radar system
- Screen 3: Conning display
- Screen 4: Radar system (back-up)
- Screen 5: Joystick control (JC) system; a basic version of the DP system
- An extra tablet is used by the captain in order to use (his own) electronic charts
- Verbal exchange about operational information preceded the transfer of command between captain and helmsman

Captain comments

- For the main console hardwired components are preferred instead of touch screen, because of their easy accessibility and to prevent fingerprints on the screen. Furthermore, this provides direct overview over all available functions, while by a display device they can be hidden by a menu
- It would be preferred to have a second chair with controls in backward position, instead of the current portable dashboard panel

Observation Zuiderzee and Waddenzee 15-12-2016
Azimuth Stern Drive (ASD) 2810 Hybrid tugs

The second user observation study was performed on two Damen Hybrid tugs of the Dutch Navy.
Observations were performed during different operations in the port of Den Helder: a boarding exercise with the Dutch Navy (Zuiderzee), the displacement of a pontoon (Waddenzee), and a towing operation to support the Zr. Ms. Rotterdam from the North Sea into the port of Den Helder. It included berthing/ unberthing, maneuvering, towing (pull), free sailing, an emergency stop (test), and the opportunity to control the vessel by myself.

The crew consists of the captain, helmsman, engineer, and deckhand.
The design and production of the bridge were performed by Damen.

Background information

- The operator’s chair is only put in backward position if there need to be sailed astern for a long period of time
- The propulsion display (at the overhead console) shows important information and is used a lot
- The control of the winch is performed by the engineer
- The screens in front are used as footrest
- One captain positioned the VHF horn with the speakers upwards by using tiewraps, because he found it easier to control it in this way than by picking up the horn. He was also not tall enough to control the VHF foot pedal.
- A hybrid tug uses three systems: batteries, mid engines, and main engines
- The harbor mode is in fact the ‘parking mode’, in the free sailing mode the batteries and/or mid engines are used, and in towing mode also the main engines are used
- The captain of the Waddenzee has 5 - 6 years’ experience as a captain
- The rotations per minute are important to know when sailing straight, since they should be the same for both thrusters
- The thruster controls give haptic feedback when they are exactly positioned at 0°, 90° or 180°. They also give proprioceptive feedback regarding how far the thruster have been displaced.
- The gauges in the overhead console give the exact position of the thrusters, which can differ from the position of the controls since these move faster than the actual propeller
- Before a towing operation starts the speed and course of the operation are communicated
- By means of hand gestures it is communicated when the tug is tightened to the relevant ship
- When sailing astern during a towing operation the operator hardly looks in backward direction. He just tries to stay in the middle of the ship in front, so in fact the tug follows the maneuvers of the other vessel. The radar and ECDIS still show potential surrounding vessels.
- Different alarms are shown in the engine room and at the bridge; only the essential alarms (for example bilge and fire alarms) are shown at the bridge
- The Praxis automation system is experienced as not fully reliable since it appeared that it does not always present the right wind direction and the right height under the keel.
- During a towing operation the most concentration of the crew is needed by: (1) attaching of the towing rope and (2) mooring of the pilot ship.

Captain comments

- There is no radio available on the bridge while this would be preferred
- A foot control is suggested to control the intercom, in order to allow for easier communication between bridge and foredeck during towing

Observation Venus 09-01-2017
Azimuth Stern Drive (ASD) 2411 tug

The third user observation study was performed on a Damen tug that is in operation for the towage company Iskes. Observations were performed during different operations in the port of IJmuiden; during daylight, dusk, and in the dark. A towing operation was performed to support the bulk carrier vessel Frontier Lodestar during mooring, and two towing operations to support the tanker Baltic Faith and the car carrier Grande Lagos through the of lock of IJmuiden. It included berthing/ unberthing, maneuvering, towing (pull and push), free sailing, loading water, and the opportunity to control the vessel by myself.

The crew consists of the captain, engineer, and deckhand. Also an additional captain in training was joining who performed two of the three towing operations.
The design and building of the bridge were performed by Damen.

Background information

- The crew works for periods of two weeks whereof they are available 14 hours a day. So these two weeks the tug also serves as their house.
- The captain of the Venus has 6 years of experience as a captain
- The captain works via the same principles as the captains of the Zuiderzee and Waddenzee
- Iskes uses the '360-control' to train their personnel; a tug simulator in IJmuiden which includes the large Damen tug consoles
- During maneuvering two thruster controls are used, during (free) sailing just one
- The resistance of the movement of the thruster controls can be configured
- Notes about the engine and propeller RPM related to the tonnage are used by the captain in training during towing operations. More experienced operators estimate the amount of power needed on basis of their experience.
- Parts of anti-slip tablemats are used on the console to prevent cups and phones from sliding of the console surface. Especially when much power is used a lot of vibration can be felt.
- The VHF horns are positioned on the ceiling
- The foot controls are placed more distant from the front window than at a 2810 tug.
- There are different VHF's available. On basis of the direction from which an incoming voice sound is heard it is reasoned to which VHF this relates and thus who is talking (pilot, shore etc.). Also the volume is set to different levels to make the distinguishing easier.

Captain comments

- The Damen bridges on the different tugs are pretty generic. This is experienced as really useful since captains can easily switch between vessels without the need to learn a new system.
- The foot controls of the winches do not have two speed ranges, while the manual controls in the console do have. Since the 'high speed function' is used a lot it is also preferred to include this function in the foot controls.
- There is no radio captured in the design of the bridge; this should be standard included

Visit Multratug31 15-03-2017
Azimuth Stern Drive (ASD) 3212 tug

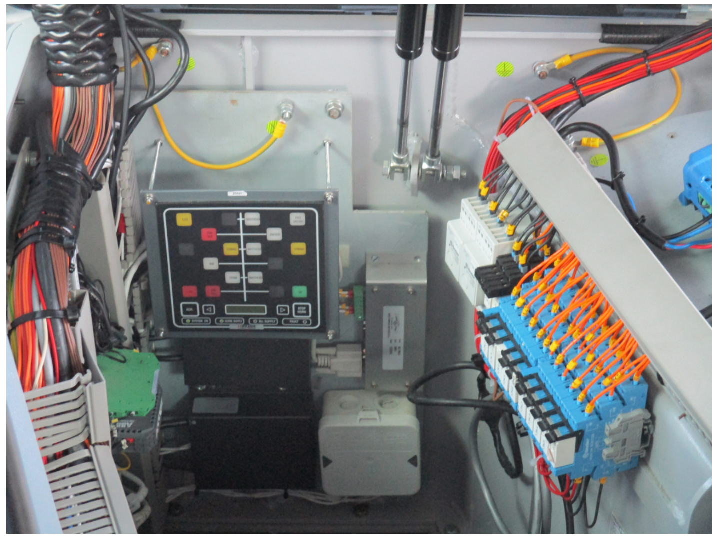
The fourth observation study was performed on a Damen tug that is in operation for the towage company Multraship. Due to servicing no observations could be performed during sailing. However an observation of the bridge, and interviews with both captains and the engineer were performed.
The design and building of the bridge were performed by Damen.

Background information

- Parts of anti-slip tablemats are used on the console to prevent cups and phones from sliding of the console surface
- The captains' chair has to be positioned at the highest level in order to provide a good view for the operator
- An extra display screen is added to show electrical charts
- The navigation lighting control panel is positioned within the console where it cannot be reached. Moreover when a light is replaced this have to be confirmed on this panel. To do this the console top have to be opened which is far from efficient.
- The 'electric' and 'diagnostics' page are not used at the bridge
- The display day vision is not used due to the bright colors that are applied; this does not work pleasant in combination with sunlight
- The amount of engine rpm is also reasoned from the haptic feedback provided by the thruster controls
- Engine load information is not used at the bridge
- Wind direction and wind speed are especially useful to know when passing the heaving line
- A dark grey background and green font are applied to increase the readability (also used on the radar screen)
- The second display generally shows the propulsion page, but during towing it shows the lighting page since turning on/off of the lights is then used a lot

Captain comments

- If the crew will be reduced to two persons, safety cannot be guaranteed at this moment. If the captain also gets the responsibility to control the winch, first the winch control has to be positioned more within reach and the type of control has to be improved.
- More view on the winch (from the side/position of the engineer) can be achieved by providing a wheelhouse that has larger bridge wings
- A pushbutton on the joystick control of the winch is preferred to activate the fast modus
- Positioning of components above the head are preferred, for example the VHF horn and radio
- The radar is sometimes shut down (also during operation) due to its radiation and the alleged effects hereof on the human health



APPENDIX F: QUESTIONNAIRE CAPTAIN

Algemeen
Naam:
Functie:
Geslacht:
Leeftijd:
Ervaring (in jaren):
Type schip:
Aantal bemanning op de brug:

Brugomgeving

1. Welke hoofdfuncties moet de brugomgeving faciliteren?
2. Welke functionaliteiten, systemen, componenten gebruik je vaak/ welke nooit? Waarom?
3. Wat zijn problemen waar u tegenaan loopt tijdens het werken op de brug? Hoe zouden deze voorkomen kunnen worden?
4. Wat zijn aspecten op de brug die behouden moeten blijven? Waarom?
5. Wordt u bij het ontwerpproces van de brug betrokken? Zou dit wenselijk zijn? Waarom (niet)? [Wanneer in het ontwerpproces?]
6. Welke aspecten zorgen ervoor dat de brug een fijne werkomgeving is/ kan worden?

Mens- machine interactie

7. Zijn de systemen begrijpelijk? Waarom wel/niet? Hoe zou dit verbeterd kunnen worden?
8. In welke informatie bent u geïnteresseerd en wanneer? Hoe verkrijgt u deze informatie het liefst? [welke eenheden?]
9. Wat als er zoveel mogelijk besturingseenheden zouden worden geïntegreerd in de stoel van de operator?
10. Wat als er alleen touch screens op de brug zouden zijn en fysieke knoppen niet meer zouden bestaan? Zie bijvoorbeeld de cockpit van figuur 2. Tot welke positieve en negatieve effecten zou dit leiden? [zelfde uiterlijk van knoppen behouden op het display?]

Trends

11. Wat zijn de effecten van de toenemende automatisering op de brug?
12. Hoe staat u tegenover het concept van een 'One man operated bridge'? En wat voor invloed zou dit hebben?

Toekomst

Hoe ziet u de implementatie van de volgende technieken op de brug? Waarom zijn deze technieken wel/niet geschikt en bruikbaar voor op de (toekomstige) brug?

13. Augmented reality; projecteren van visuele informatie
14. Holo lens; projectie van een hologram
15. Bediening door middel van gebaren (hover sensing)
16. 3D representatie of verschillende schepen en hun tracks
17. 'Google streetview' op zee, dus de mogelijkheid om vooraf bepaalde havens/ gebieden te bekijken op een display

18. Hoe ziet u de brug over 10 jaar?

APPENDIX G: USABILITY ISSUE OVERVIEW

Vessel	Category	Issue	Cause	Root cause
FYS 5009	A	The different dashboard panels are not aligned relative to each other	The focus is on the availability of equipment rather than the positioning and its appearance, also due to time pressure	Knowledge
FYS/ ASD 2411	PE	Much space of the bridge is occupied by the consoles, chairs and workstations; there is less room to move around for the crew	A standardized bridge design is applied, which is not completely adapted to the dimensions and layout of this bridge	Business
FYS 5009	PE	The indication lights for several components are very small and can hardly be noticed	Indication lights are part of specific components that are purchased from a supplier. The indication lights are not designed within the context of the bridge environment	Business/ Knowledge
FYS 5009	PE	Inefficient use of space of the console surface; parts are left open in an inconsistent way	A standard arrangement of equipment is defined; if a customert does not want specific components they are left out without rearranging the remaining components	Business/ Knowledge
FYS 5009	HMI	The function of different component groups is not clear	The separate components are designed apart from eachother. By placing them together it is hard to distuinguish their functions	Business/ Knowledge
FYS/ASD tugs	HMI	Less consistency between hardware and software design, for example the indication of the compass	Components of different suppliers are used which do not match each other	Business
FYS 5009	HMI	Less consistency in the output of operating controls, for example the hardwired steering levers lead to another output than the wireless steering levers (of the separate control panel)	Different suppliers use different principles and do other assumptions about how the equipment is going to be used. Damen makes no demands in this field	Knowledge/ User involvement
FYS/ASD tugs	PE	Less space for own equipment like a laptop	The bridge is designed around the equipment that has to be included. There is less insight in how the environment is exactly used.	Knowledge
FYS 5009	PE	Power sockets are rarely available close to the operator (for example to charge a laptop)	It is not taken into account that the operator spends a lot of time on the bridge (on the same position); i.e. less understanding of the actual use situation	Knowledge
Eco Liner 1145	PE	The interface is inadequate in its operational support; for example several buttons are not visible by night	Less understanding of all operational conditions and their effects	Knowledge
ASD Tug 2810	HMI	Non meaningful textual expressions and abbreviations are used on displays and buttons	Less understanding of the mental model of the user	Knowledge/ User involvement
ASD Tug 2810	HMI	Too much text is applied within the graphical user interface of the main display device	Less understanding of the operational use of the system	Knowledge
ASD Tug 2810	PE	The console surface and the mounted control panels are not at the same height while they should be; this causes sharp edges	Sloppy manufacturing finish due to time pressure	Business
ASD Tug 2810	PE	Controls positioned in the passageway are almost impossible to control because of their transparent shielding plate	The focus is on how the components can be included without taking into account their actual use	Knowledge
ASD Tug 2810	A/ HMI	The functions and priorities of input controls cannot be recognized by their appearance, for example emergency stop controls are not easy to distinguish from regular controls	The separate input controls are designed apart from eachother. By placing them together it is hard to distuinguish their functions	Business/ Knowledge
ASD Tug 2810	PE	The holder of the ECDIS keyboard is not suitable since buttons are pressed unintendedly (and settings are changed) when the keyboard is placed in its holder	The focus is on how the keyboard can be stored without taking into account its actual use	Knowledge
ASD Tug 2810	PE	The ECDIS keyboard is not wireless which makes it unhandy to operate. It also imposes a risk that the wire gets entangled with the thruster control	The choice of the keyboard is not taken with the actual use situation in mind. There is also less understanding of the interrelations between components during use	Knowledge
ASD Tug 2810	HMI	Some graphical representations of information on the graphical user interface are not clear, for example the wind	Less understanding of the mental model of the user	Knowledge/ User involvement
ASD Tug 2810	HMI	Crucial system calibration settings can be changed by all crew. For example the audible signal of emergeny alarms can be easily switched off	Less insight in improper use and less understanding of the risks that are involved when the system is not used as intended	Knowledge/ User involvement
ASD Tug 2411	PE	The small seats close to the side windows are uncomfortable, especially when used for a longer period of time	The seats do not have a high priority. There is also less insight in their actual use situation	Business/ Knowledge
ASD Tug 2411	HMI	Real-time information is not shown in real time on the information display, for example engine power levels. Therefore this kind of information is less useful	Focus on the availability of the function instead of the actual functioning. Damen does not demand a certain processing speed of the Praxis automation system	Business
ASD Tug 3212	PE	The conditions to control the aft winch in a pleasant and efficient way are lacking; there is no proper view on the aft winch, and less information is provided in aftwards direction	ASD tugs contain more often a fore winch than an aft winch. Therefore the design is more adapted to the use of the fore winch	Business/ Knowledge
ASD tugs	HMI	The interface shows irrelevant information for the task, for example the quality of the GPS is continuously shown on the main display	Less understanding of the kind of information the operator is interested in and in which situations	User involvement
ASD tugs	HMI	The winch foot controls are hardly used since the captain is too busy with maneuvering and communication tasks during towing operations	Less understanding of the context of use of the foot controls	Knowledge
ASD tugs	PE	Not all equipment is within reach for small persons, for example the emergency steering controls and foot controls	The user and actual use of the ccmponents are not fully taken into account	Knowledge
ASD tugs	HMI	Display devices and groups of components need to be dimmed separately; this takes a lot of time if the entire bridge area need to be dimmed	Components and systems of different suppliers all provide their own dimming function. The bridge is not designed as an integrated entity	Business
ASD tugs	HMI	Communication between the bridge and the fore deck by means of the intercom is hard since it needs to be controlled by hand, while the captain needs its hands to maneuver the vessel	Less understanding of the actual use situation and context of use	Knowledge
ASD tugs	PE	The foot controls are not within reach when the footrest of the chair is unfolded (i.e. in horizontal position)	The interrelations between different components on the bridge are not taken into account	Knowledge
ASD tugs	HMI	The main touch screen devices are less used because they react slowly	Focus on the availability of the touch screen instead of the actual functioning. Damen does not demand a certain reaction speed	Business
ASD tugs	PE	The light intensity of two buttons for the emergency winch release are not dimmable which is annoying during night	The control buttons are purchased separate and it is assumed that they work well	Business/ Knowledge
ASD tugs	PE	When sailing astern the chair cannot be placed within reach of the thruster controls since the foot controls obstruct this. Maneuvering have to be performed in standing position with the chair in the line of sight	The interrelations between different components on the bridge are not taken into account	Knowledge
ASD tugs	HMI	Control of the winch works devious; the functions of several buttons are not immediately clear	The winch control panel is developed by a supplier. Damen did not test the usability of this system.	Business/ Knowledge
ASD tugs	PE	The frequency of use of information items does not match the positions at which the different information items are	There is less understanding of the frequency of use of different information items	Knowledge
All	**A/HMI**	**Less consistency in bridge design, its interfaces, and components on a vessel. Also large differences among different Damen vessels**	**The different Damen Product Groups choose their own suppliers who use different styles, graphical repesentations, and principles**	**Business**
All	HMI	Text of the graphical interface is hard to read when a small font size is applied	A certain font size is standard applied, regardless of the type of ship it is used for	Business
All	**PE**	**The frequency of use of components does not match their positioning and arrangement (in a consistent way) within the wheelhouse**	**There is less understanding of the frequency of use of different components and the operational procedures**	**Knowledge**
All	**HMI**	**A lot of information is available which makes it hard and time consuming to find the right information**	**More functions and information become digitally available but there is less overview of the priority of the different information items**	**Knowledge**
All	**HMI**	**The interface is inefficient in its mechanism of interaction. For example 'easy' tasks like controlling the window wipers and flood lights require a lot of actions on the display device**	**There is less understanding of the frequency of use and priority of different functions**	**Knowledge**
All	HMI	Less feedback is provided on the display devices, for example about selections that are made	The user interface is designed from technical perspective whereby certain design principles are not taken into account	Knowledge
All	**HMI**	**The interface provides less situational support. For example a lot of information is 'known' by the automation system (for example the sailing direction) but it is not applied to support the operator**	**The main priority is to include the system functionalities that are needed, mainly due to time pressure**	**Business**
All	A/HMI	Several different display devices are applied which all have their own input device	Separate devices of different suppliers are applied	Business

Category legend
Physical ergonomics (PE): relates to reachability of components, positioning of equipment and overall layout, the design (shape) of equipment, and inner and outer visibility
Human-machine interaction (HMI): relates to cognitive ergonomics, organizational ergonomics, and (graphical) user interface design
Appearance: relates to visual characteristics and design

APPENDIX H: MARKET RESEARCH

An overview is presented of different bridge solutions that are currently available on the market. Moreover some inspiration is provided by interface applications of the car industry.

Ship bridge solutions

Rolls Royce Unified Bridge

Rolls Royce Marine developed a new bridge environment solution: the Unified Bridge, see figure 48. The consoles are modular and a lot of functions can be controlled from one position. The aim of this redesign is to improve comfort and performance and thereby increase safety (Rolls-Royce, 2017).

Figure 48: Unified bridge solution Rolls-Royce Marine (Rolls-Royce, 2017)

K-Master Kongsberg

The Kongsberg K-master integrated bridge workstation is developed for luxury vessels. The aim is that operators can control the vessel from one single seated position (Kongsberg Maritime, n.d.).

Figure 49: Integrated bridge workstation Kongsberg (Kongsberg Maritime, n.d.)

Alphabridge Alphatron

Alphatron developed the Alphabridge concept, an integrated bridge solution with modular consoles. Figure 50 shows the Alphabridge tugboat solution. The displays can be pulled down if they are not used.

Figure 50: Alphabridge tugboat solution (Horn International, n.d.)

Yachting bridge console Radio Zeeland

Figure 51 shows a yachting bridge console of Radio Zeeland DMP with integrated equipment of Raytheon Anschütz. The control panels are finished with a glass top plate (Radio Zeeland DMP, n.d.).

Figure 51: Yachting bridge console Radio Zeeland DMP (Radio Zeeland DMP, n.d.)

It can be concluded that interaction components that are currently applied within common ship bridge interfaces are:

- Display devices with manual or touch screen control
- Hardwired buttons
- Soft keys
- Touchpads
- Trackballs
- Joysticks
- Control levers

APPENDIX I: AREAS OF INTEREST

Figure 52 shows different factors that are related to human factors and the bridge environment. The specific areas that are included in the research scope are highlighted.

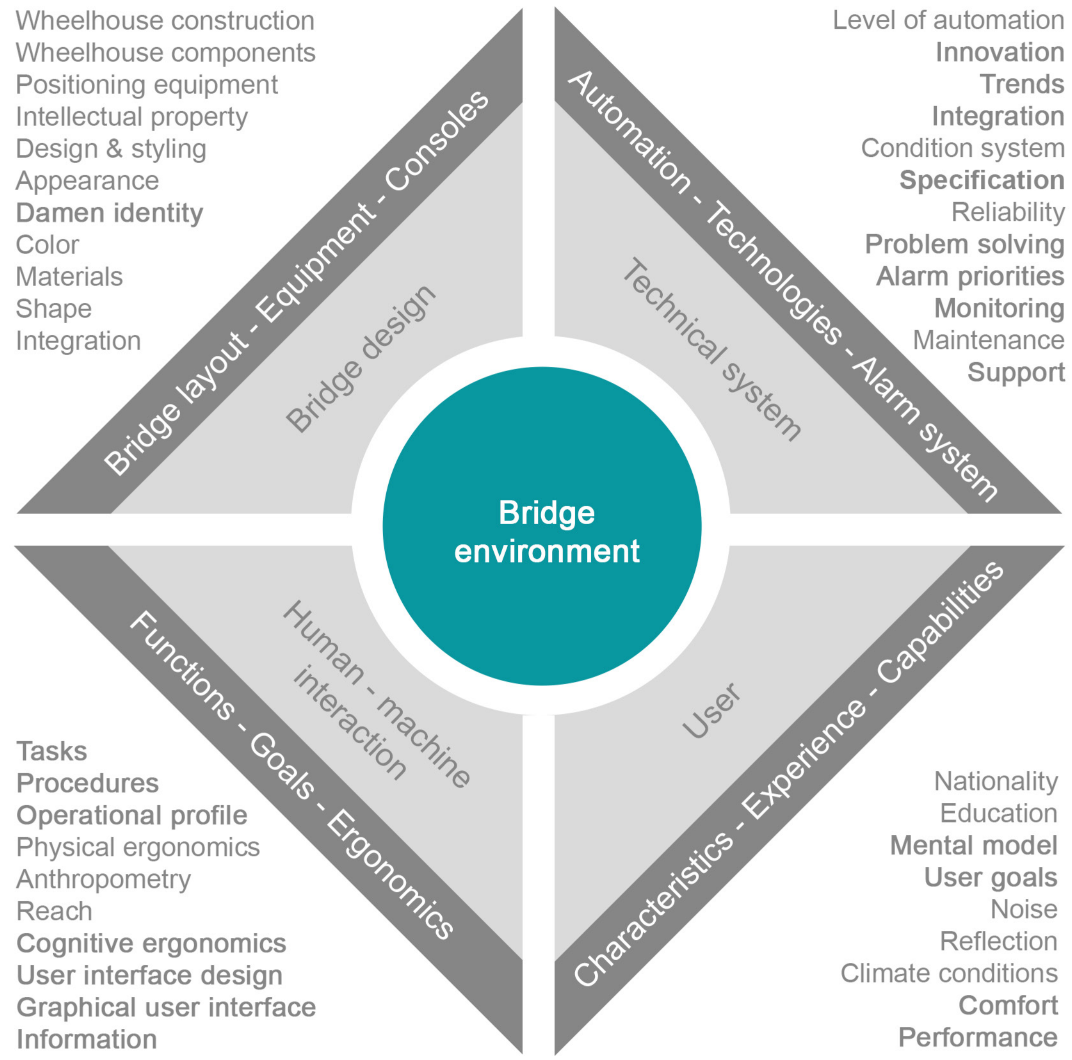


Figure 52: Research scope within areas of interest

Figure 53 shows the organization chart of the Damen Gorinchem business unit Workboats.

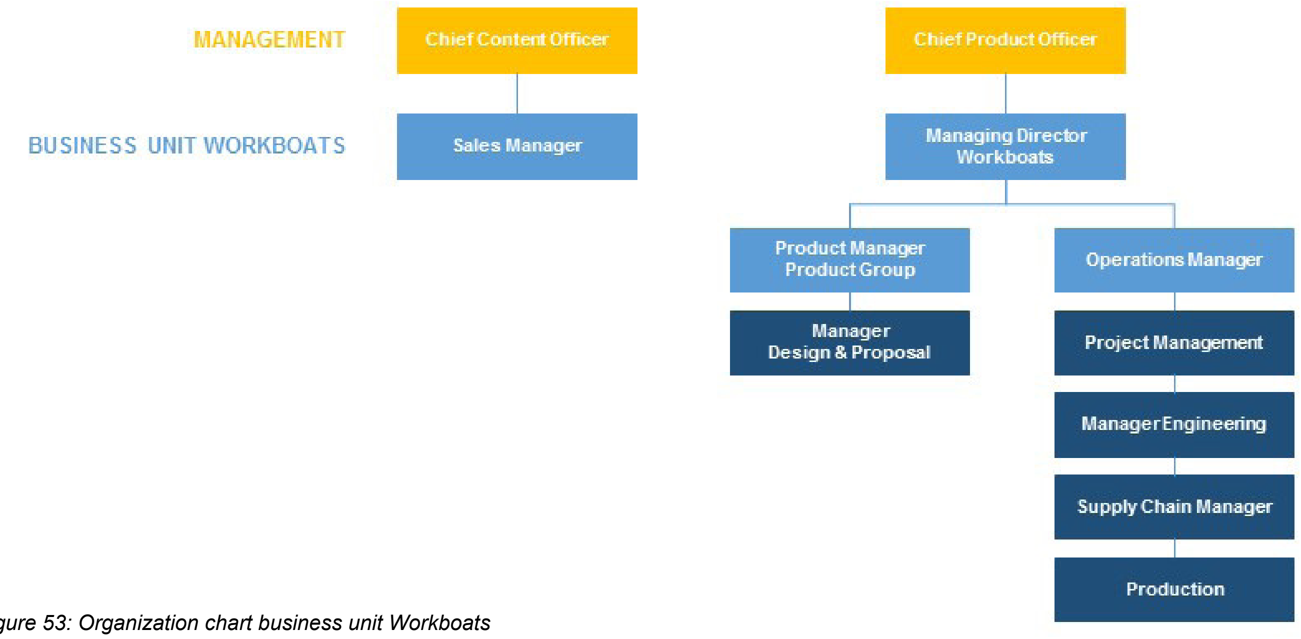


Figure 53: Organization chart business unit Workboats

The Product Group is responsible for development, definition, and implementation. This applies to processes like innovation, standardization of systems and components, quality definition, and portfolio management of the product, systems, and components.
Operations is responsible for the engineering, purchasing, and production with the objective to reduce lead time and to improve quality and efficiency.
A specific wharf is responsible for the actual production.

APPENDIX K: INFORMATION ITEMS

The information items that are used during the card sorting method are listed below.

1. Engine load
2. Rudder/thruster angle
3. Engine RPM
4. Propeller RPM
5. Position in GPS coordinates (latitude/ longitude)
6. Heading
7. Rate of turn
8. Pitch
9. Roll
10. Distance and time to wheel over position
11. Course over ground
12. Wind speed and direction
13. Engine information: exhaust gas temperature, oil levels, coolant temperature
14. Speed over ground
15. Speed through water
16. Depth under keel
17. Trend of depth
18. Pump status per pump: running/failure/stopped
19. On/off indication exterior lighting (navigation lights, flood lights)
20. Day/night status
21. Generator status: running/failure/stopped
22. Generator information: frequency, current, power, efficiency
23. Shore supply information: current, voltage
24. Battery information: voltage and charging indicator
25. Tank information: position tanks within the vessel, percentage filled per tank
26. Hour counters
27. Fuel consumption
28. Description and cause of emergency alarms and alarms
29. Description and cause of warnings and cautions
30. Indication steering mode: manual/ autopilot
31. Course to steer
32. Actions to be taken in case of alarms
33. Notifications of preventive actions to be taken
34. Indication of control: engine room/main deck/wheelhouse
35. Meteorological forecasts
36. Air temperature
37. Warnings on collisions
38. Information about currents and tides
39. Predetermined route and its waypoints
40. Surrounding ships and their course and speed
41. Closest point of approach (CPA) of objects and vessels
42. No-go areas
43. Overview watertight doors and hatches open/closed
44. Overview fire doors open/ closed
45. Radar
46. AIS
47. Electronic chart
48. Magnetic compass
49. Angle of towing rope
50. Pay-out length of towing rope
51. Bollard pull (in tons)
52. Speed of the towed vessel
53. Course of the towed vessel
54. Braking force winch
55. Date
56. Time
57. Estimated time of arrival

APPENDIX L: INFORMATION MANDATORY BY CLASS

The required information is specified by the regulatory bodies Lloyd's Register, Bureau Veritas, and DNV GL, as outlined in table 3.

Subject	Information compulsory by Class
Propulsion (show for PS and SB)	Indication of control
	Engine RPM
	Propeller RPM
	Rudder/Thruster angle
Engine (show for PS and SB)	Coolant temperature
	Fuel oil delivery pressure
	Fuel oil filter differential pressure
	Oil pressure
	Oil temperature
	Fuel pressure
	Exhaust gas temperature individual cylinders
	Manifold exhaust temperature SB + PS
Alarm	5 lines Emergency Alarm
	14 lines Alarm
	8 lines Warning
	4 lines Caution
Generator (show per generator)	Voltage indicator
	Frequency indicator
	Current indicator
	Power indicator
	Efficiency
	Busbar Voltage
	Busbar Frequency
Shore supply	Current indicator
	Voltage indicator
Battery (show per battery)	Voltage indicator
	Earth fault indicator
	Charger fault indicator
Fire (show in case of fire)	Layout of ship decks / fire zones
Open/closed doors and hatches	Doors and hatch arrangement which are monitored

Table 3: Information required by Classification

The indication of differing alarm conditions is as follows (IMO, 2004):

- Active (emergency) alarm status: red, blinking, and audible
- Active (emergency) alarm status acknowledged: red, blinking (cancelling the audible alarm)
- Active warning / caution message: orange, static
- Normal condition: no light (indication of a safe situation)

APPENDIX M: RESULTS CARD SORTING

Additional remarks that resulted from the card sorting sessions are outlined below.

- The depth under keel is more important for category 1, since the waters are more shallow in these areas
- The time has to be shown continuously since it is used for reporting activities
- The difference between the values of the speed over ground and speed through water indicates how strong the current is
- The course over ground and position are not relevant for category 1, since the course and position are determined on basis of quays and other landmarks on the shore
- The course to steer is only relevant for large vessels, and is only applicable if waypoints are used
- The values of position coordinates make more sense if they are shown in combination with a chart
- The rate of turn, a predetermined route (with waypoints), and the distance and time to wheel over position are only relevant for (very) large vessels
- Information about currents and tides is particularly useful for the journey preparation
- The thruster pitch is only useful for vessels with controllable pitch propellers
- There is more need for a clear description of the cause of alarms, instead of actions that have to be taken. A better description will also lead to the right actions in the end.

Information that is indicated as irrelevant:

- A day/night modus indication, this can be noticed by looking outside
- The angle of the towing rope, this can be monitored by looking outside. Furthermore it is currently not possible to measure this angle in a reliable and cost effective way.
- The course of the towed vessel (in case of a tug), since the tug follows the course of the vessel. Moreover the destination of the vessel is known by the captain so the course can be reasoned.

APPENDIX N: BACKGROUND INFORMATION TUGS

This information is a combination of own field research and earlier research for the master's thesis of L. Klink (2012) for Damen.

Tugboat assistance

The purpose of a tug is to assist other vessels during maneuvers. This can be done via three methods:

1. **Towing on a line;** one or two tugs are attached at the bow and/or at the stern of the vessel that needs assistance, see figure 54.
2. **Operating at a vessel's side;** tug(s) are positioned at one side of the assisted vessel to push against the hull of it or to pull on the line. This is called a push-pull configuration, see figure 55 and 56.
3. **Escorting**; the tug is positioned behind the assisted ship in order to add maneuverability to it or to stop the ship, see figure 57. Hereby the pay-out length of the towing rope is relatively long. Escorting is mostly performed in open waters.

Often a combination of these methods is applied during a towing operation, for example towing on a line to assist a vessel into the harbor and tugs pushing to assist a vessel into a berth.

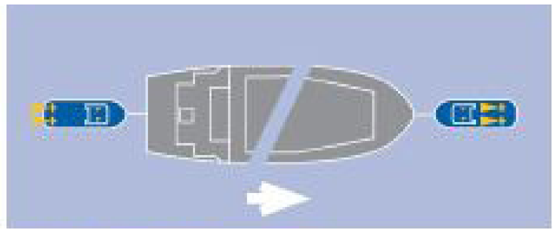


Figure 54: Normal towing procedure (Klink, 2012)

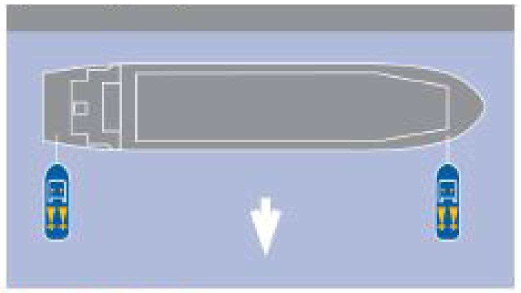


Figure 55: Tugs pulling (Klink, 2012)

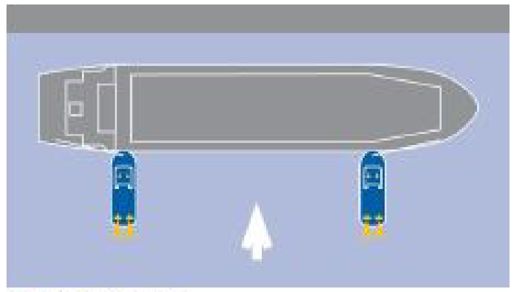


Figure 56: Tugs pushing (Klink, 2012)

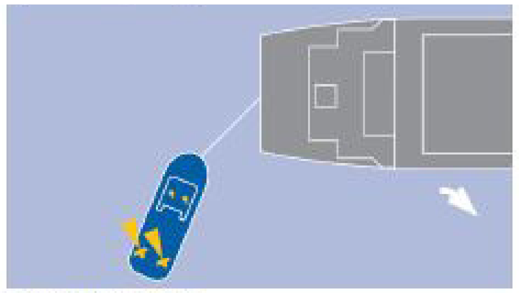


Figure 57: Tug escorting (Klink, 2012)

Crew

For this project the amount of three crew members is taken: a captain, engineer, and deckhand. However the number of crew members differs per harbor and country.

Towing procedure

A towing procedure consists of four general steps, see also figure 58-61:

1. **Meeting the vessel**
   Radio contact between the tug and the pilot is established before the operation starts and while the tug is on its way.
2. **Attaching the towing rope**
   Most assisting is performed with a rope connection between vessel and tug. First, the captain maneuvers the tug closely to the vessel and the deckhand passes a lightweight heaving line from the tug to the vessel. The heaving line is connected to a stronger messenger line, which in turn is connected to the (heavy) towing rope. During this procedure the tug and vessel come close to each other while moving, which makes it the most dangerous procedure in towing. When the assisted vessel has a large hull, it is needed that the tugboat 'crawls under' the vessel. In this situation the captain has to make sure that the mast will not hit the hull of the vessel.
   To avoid collisions the tug captain needs to match the speed of the vessel that is assisted while compensating for wind, current, and propeller wash or bow wave.
   In a harbor environment tugboat captains have to follow the pilot's instructions since the pilot is in charge of the towing operation. An ASD tug often uses a bow winch to perform towing. In this way the chance of getting a line in one of the propellers is reduced. Furthermore, distance between the tug's propellers and the vessels' bow is maximized. In this way the tugs' propeller wash does not directly push the vessel back which increases the efficiency of the operation.
3. **Assisting the pilot vessel**
   Tugs can give steering assistance, control the pilot ship's speed, compensate for wind and current, and control transverse speed while berthing. During assistance the pilot continuously communicates the percentage or amount of pulling/pushing force that is needed to the tug captain. By using the bow winch the captain mainly looks in forward direction, even when sailing astern. By using the aft winch the captain mainly looks in aft wards direction and controls the thrusters in standing position. The engineer controls the aft winch by means of the portable control panel.
   During towing a lot is going on at the same time. In addition to the tasks related to maneuvering, the captain needs to monitor the towing rope and winch and needs to communicate with its crew and the pilot.
4. **Detaching the towing rope**
   When the assist is successfully performed, the rope connection no longer has to be continued. The tug will come close to the relevant vessel and the towing rope can be detached, whereafter it will land on the deck of the tug.

Figure 58: Tug on its way to the pilot vessel

Figure 59: Attaching the towing rope

Figure 60: Assisting the pilot vessel

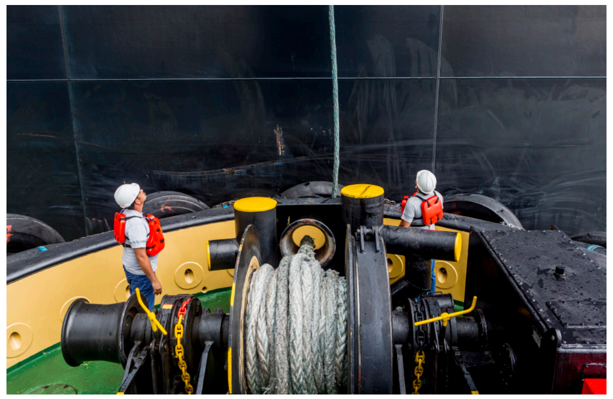


Figure 61: Detaching the towing rope

APPENDIX O: USABILITY TESTING

Test setup

Figure 62 shows the arrangement within the Damen meeting room. Natural lighting on the display device is provided by means of the window.

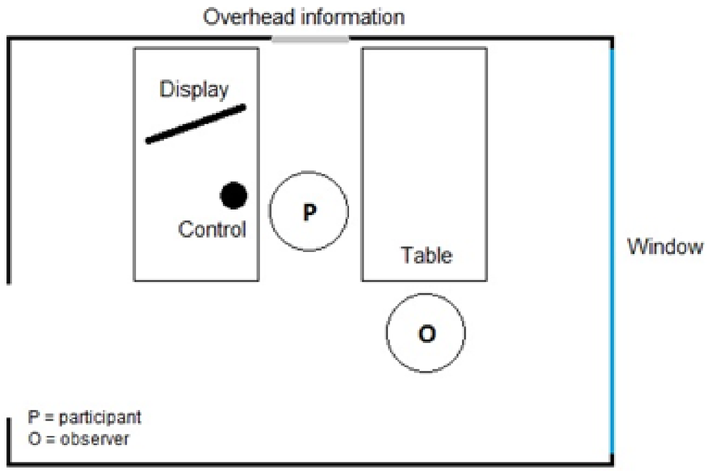


Figure 62: Test set-up

The prototype consists of a touch screen display (17 inch), whereon the interactive prototype (within PowerPoint) is shown. The prototype can be controlled by means of touching the screen or by using the mouse.
On the display there can be navigated through the menu, its submenus, and their related pages. The conning page or 'mimic' is graphically worked out whereby the design guidelines are applied. For the other pages the rough division of the relevant information (wireframe) is indicated.
Situation specific information is shown on a small display device (7 inch tablet) which is placed overhead.

It is preferred to let prospective (actual) users participate since they will provide the most useful feedback; they are the experts in this field. However when there are not many tug captains available it can be chosen to include other participants as well, for example project managers.

The following activities are performed during a test session:
1. Introduction + explanation
2. Testing; performing tasks
During the test participants have to perform specially devised tasks while interacting with the prototype. The tasks are outlined by means of task descriptions. Participants have to think out loud while performing tasks, to provide immediate (qualitative) feedback.
The tasks apply to core tasks (frequently performed by users), new functionalities, and critical tasks:

1. Show conning information related to the harbor environment
2. Change the modus of control to the wheelhouse
3. What is the true wind direction?
4. What is the relative wind direction?
5. Which doors are open?
6. Get rid of the information about the doors
7. Try the different navigation light modi, and choose sailing mode
8. Get rid of the information about the navigation lights
9. Change the attendance of the engineer
10. Hide the trending depth
11. Go to the Damen contact page
12. Go to the help function
13. Imagine you are in a towing operation. What is the current pay-out length of the towing rope?
14. What is the speed of the towed vessel?
15. Which drum is selected?
16. Go to the tank information page
17. Find out more about the given warnings
18. Return to the conning page

3. User observation
The observer (Myrthe) will directly observe the interaction between the participant and the prototype. The observer will also record observations and the speed of task execution, and will count the amount of errors made.

4. Evaluation
Post-test questionnaire
By means of a questionnaire answers can be compared, which leads to quantitative data.
On a five point scale, the participants have to indicate:

- The degree to which the tone and style of the interface makes it pleasant to use
- The degree to which the structure of the system is clear
- The degree to which the capabilities of the system are clear
- The degree to which the system provides enough feedback according to actions that are performed
- The degree to which the system provides the right feedback according to actions that are performed
- The degree to which the meaning of the icons is clear
- The degree to which the system works efficient, i.e. less steps has to be taken to perform tasks
- The degree to which the mimics have a calm appearance
- The degree to which the information on the overhead display is of added value
- The degree to which the information is shown at the right place on the main display screen
- The degree to which the information is shown at the right place within the wheelhouse

Additional open questions
The closed questions of the questionnaire give little information about why users have answered in the way they have, so therefore also open questions are asked after the questionnaire is filled in. This can give insight in the cause of issues that might have happened and how these can be solved.