

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Human-centred design for maritime technology and organizational change

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Abstract

Context: The shipping industry is undergoing a transitional phase at different levels, including IMO's e-Navigation initiative, and with this comes the need to use a human-centred design (HCD) approach to avoid accidents linked to automation issues, and to cater for the maintenance of safety and efficiency within this global transport system.

Aims: The aim of this thesis is to investigate the value and challenges in HCD practice and how ergonomics/human factors (E/HF) principles can be introduced, as well as what gaps and opportunities exist in current standard operations and technologies in navigation that can potentially be followed upon by future e-Navigation developments, not only from a technological perspective but also regulatory, operational etc.

Methods: This thesis derives from the work of six appended articles that mainly utilized a qualitative approach to data collections, including focus groups, interviews and observations, and to data analyses, such as narratives and a grounded theory approach. In total, two design teams and four separate sets of onboard and shore-based operators were consulted for data collection.

Results: The results from the appended papers suggest that user involvement in design as well as in rule making and purchasing of new ship equipment was perceived as important for a good work environment, and efficient and safe operations onboard in this safety-critical industry. The results show that design projects are situated experiences that involve complex tasks and resource management, and that require re-iterative adaptations throughout the process. In involving the users and implementing E/HF methods, support from the management is needed and professional E/HF expertise should be a part of the team to help interpret E/HF methods and guide the process to foster continuous knowledge sharing within the team, the organization and with the users from an early stage. When investigating current operations and technologies in navigation, it was evident that gaps exist that can be improved by the redesign of current technologies or the implementation of novel e-Navigation solutions. For example, there is a large number of unintegrated systems and information sources today, and everyday routines and information across geographical areas and communication channels are not unified. Technology concepts and developments towards the e-Navigation principles have been considerably debated, yet there are still gaps that can be filled, and despite e-Navigation's principle for HCD, the holistic – macro – perspective of the development of these new technologies seems to be under-exploited.

Conclusions: Filling the existing gaps with available novel technologies is not enough to guarantee efficiency and safety in the domain, nor to guarantee acceptance. A more systemic perspective is needed, of how the different people and processes in the sea transport system can be affected by the introduction of new technology in terms of how work is performed, of regulations, new training and re-skilling, as well as of preparation for new issues that may arise with increased automation such as workload and cyber-security. This work points at the value and practice of E/HF and systems-driven design, and directs it at change makers and opinion leaders: designers, managers, rule-makers, educators, to consider the human element for safety and efficiency. In this transitional stage, one of the great values of E/HF is to more proactively prepare the shipping industry for the ongoing e-Navigation changes rather than having the industry adapt operations, regulations, training and plan the sustainability of the transport system *ad hoc* after technology implementation.

Keywords: human-centred design; participatory ergonomics; systems theory; organizational change; technology acceptance; digitalization; e-Navigation.

Acknowledgements

I would like to acknowledge the funding organizations that supported the work in this thesis, namely the CyClaDes project from the European Union's Seventh Framework programme [grant nr. 313972, <http://www.cyclades-project.eu/CyClaDes/>], and the EfficienSea2 project from the European Union's Horizon 2020 programme [grant nr. 636329, <https://efficiensea2.org/>].

A special thank you to my supervisors Professor Scott MacKinnon and Dr. Monica Lundh, as well as to Dr. Joakim Dahlman for their continuous guidance and support. I also want to thank Professor Margareta Lützhöft, Professor Margareta Ljung and Professor Thomas Porathe for their supervision at an earlier stage of my PhD studies. I want to thank all former and current colleagues from the Maritime Human Factors group, Reto Weber, the administrative group, and the overall Shipping department for the fellowship and support in the past five years. I want to thank all my co-authors and study respondents, the CyClaDes and EfficienSea2 teams for the work we did together, the colleagues at PPU and course teachers I have had along the way.

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Appended Articles

List of Appended Articles

This thesis is based on the research contained in the following articles, referred to by Roman numerals in the text:

- Article I** Costa, N., de Vries, L., Dahlman, J., & MacKinnon, S. (2015). Perceived success factors of participatory ergonomics in ship design. *Occupational Ergonomics*, 12(4), 141-150. doi:10.3233/OER-150230
- Article II** Costa, N. A., Vesting, F., Dahlman, J., & MacKinnon, S. (2019). A case study of user adherence and software project performance barriers from a sociotechnical viewpoint. In T. Ahram (Ed.), *Advances in Artificial Intelligence, Software and Systems Engineering. AHFE 2018. Advances in Intelligent Systems and Computing* (Vol. 787, pp. 12-23): Springer, Cham.
- Article III** Costa, N. A., Holder, E., & MacKinnon, S. N. (2017). Implementing human centred design in the context of a graphical user interface redesign for ship manoeuvring. *International Journal of Human-Computer Studies*, 100(2017), 55-65. doi:10.1016/j.ijhcs.2016.12.006
- Article IV** Costa, N. A., Lundh, M., & MacKinnon, S. N. (2018). Identifying gaps, opportunities and user needs for future e-navigation technology and information exchange. In N. Stanton (Ed.), *Advances in Human Aspects of Transportation. AHFE 2017. Advances in Intelligent Systems and Computing* (Vol. 597, pp. 157-169): Springer, Cham.
- Article V** Costa, N. A., Lundh, M., & MacKinnon, S. N. (2018). Non-technical communication factors at the Vessel Traffic Services. *Cognition, Technology & Work*, 20(1), 63-72. doi:10.1007/s10111-017-0448-9
- Article VI** Costa, N. A., Jakobsen, J. J., Weber, R., Lundh, M., & MacKinnon, S. N. (under review). Assessing a maritime service website prototype in a ship bridge simulator: Navigators' experiences and perceptions of novel e-navigation solutions. *Manuscript submitted for publication in WMU Journal of Maritime Affairs*.

Nicole A. Costa is the first and main author of all appended articles, developed with the support of the co-authors through a series of iterations.

Other Publications

The following publications have also been part of the author's doctoral research work although not included in this thesis:

Peer-Reviewed Journal Articles

de Vries, L., Hogström, P., Costa, N., & Mallam, S. (2017). Designing for safe operations: Promoting a human-centred approach to complex vessel design. *Ships and Offshore Structures*, 12(8), 1016-1023. doi:10.1080/17445302.2017.1302637

Vesting, F., Bensow, R. E., Johansson, R., Gustafsson, R., & Costa, N. (2016). Procedure for application-oriented optimisation of marine propellers. *Journal of Marine Science and Engineering*, 4(83). doi:10.3390/jmse4040083

Peer-Reviewed Conference Proceedings

Costa, N., & Lützhöft, M. (2014). *The values of ergonomics in ship design and operation*. Paper presented at the International Conference on Human Factors in Ship Design & Operation, 26-27 February 2014, London, UK.

de Vries, L., Costa, N., Hogström, P., & Mallam, S. C. (2015). *Overcoming the challenges of integration of Human-centred Design within the Naval Architecture ship design process*. Paper presented at the 19th Triennial Congress of the IEA 9-14 August 2015, Melbourne, Australia.

Man, Y., Lützhöft, M., Costa, N. A., Lundh, M., & MacKinnon, S. N. (2018). Gaps between users and designers: A usability study about a tablet-based application used on the ship bridges. In S. N. (Ed.), *Advances in Human Aspects of Transportation. AHFE 2017. Advances in Intelligent Systems and Computing* (Vol. 597, pp. 213-224): Springer, Cham.

Peer-Reviewed Book Chapters

Costa, N., de Vries, L., & Dobbins, T. (2015). Introduction to human-centred design for naval architects and designers. In T. N. Institute (Ed.), *Improving Ship Operational Design* (2nd ed., pp. 3-16). UK: The Nautical Institute.

Technical Reports

Costa, N. A., & de Vries, L. (2015). *Introduction to human-centred design for naval architects and designers*. Chalmers University of Technology, Gothenburg, Sweden. (R 15:159)

Academic Theses (Licentiate Thesis)

Costa, N. (2016). *Human centred design for maritime safety: A user perspective on the benefits and success factors of user participation in the design of ships and ship systems*. (Thesis for the Degree of Licentiate of Philosophy), Chalmers University of Technology, Gothenburg, Sweden. (16:162)

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List of Abbreviations

ACD	Activity Centred Design
AIS	Automatic Identification System
COLREGs	International Regulations for Preventing Collisions at Sea
CPA	Closest Point of Approach
CyClaDes	Crew-Centered Design and Operation of Ships and Ship Systems
E/HF	Ergonomics and Human Factors
ECDIS	Electronic Chart Display and Information Systems
ENC	Electronic Navigation Charts
HCD	Human-Centred Design
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IEA	International Ergonomics Association
IMO	International Maritime Organization
INS	Information Service (VTS)
ISM	International Safety Management
ISO	International Organization for Standardization
IT	Information Technology
MARPOL	Prevention of Pollution from Ships
MSI	Maritime Safety Information
NAS	Navigational Advice and Assistance Service (VTS)
Navtex	Navigational Telex
SAR	Maritime Search and Rescue
SMA	Swedish Maritime Authority
SOLAS	International Convention for the Safety of Life at Sea
SQA	Software Quality Assurance
STCW Manila	Standards of Training, Certification and Watchkeeping for Seafarers
TOS	Traffic Organization Service (VTS)
UCD	User Centred Design
UT	Usability Testing
UX	User Experience
VHF	Very High Frequency
VTS	Vessel Traffic Services
VTSO	Vessel Traffic Services Operator

1 Introduction

We find ourselves in a fast-changing era of global and exponential propagation of automation and information digitalization. In this revolutionary time, the international shipping industry is no exception to the rule (Bhardwaj, 2013) and is currently undergoing the increased demand, challenge, and transition into more information exchange and interconnectivity between ships and shore, higher productivity and emissions reduction stemming from international directives for the purpose of safety, efficiency and environmental protection (de Vries, 2015; Earthy & Lützhöft, 2018), even if the shipping industry can be generally slow and conservative in these respects (Earthy & Lützhöft, 2018; Man, Lundh, & MacKinnon, 2018a). These demands are usual motives to introduce new automation onboard. Yet, new technology, rather than aid the operators at work, can instead create negative consequences or not be adopted if not perceived usable, useful and as value added (Chen & Huang, 2016; Grech, Horberry, & Koester, 2008; Ma, Chan, & Chen, 2016; Mallam, Lundh, & MacKinnon, 2017; Schepers & Wetzels, 2007). This is where ergonomics/human factors (E/HF) considerations in design come in to include those who will be affected by innovations and change, who can help design those innovations and changes to be more suitable to user needs and contexts, for a safer and more efficient future in the domain. There are guidelines to how design can account for such considerations (e.g., ISO, 2010), but this thesis will discuss how each project requires its own adaptations and contextualization for maximized learning and knowledge mobilization, as well as the impacts of novel technology from a larger systems perspective. These endeavours in the maritime domain can be especially challenging as this is a unique industry (Costa, 2016; Mallam, 2016; Manuel, 2011; Österman, 2012) of isolated and harsh work environments for prolonged periods of time, distributed stakeholders, hierarchical structures, multicultural crews, and limited team-based training (Manuel, 2011).

1.1 Research Background

This thesis is part of the author's doctoral research programme carried out during 2013-2018. It was established to study, promote and support the increased impact of the human element and the use of the human-centred design (HCD) approach and mindset in the design of ships and ship systems, mainly in commercial shipping. This was done by investigating the design approach in context and proposing an interpretation and toolbox to facilitate its practice. The ultimate goal was to design onboard environments, routines and systems to better support those running the operations, improve their working and living conditions, and optimize the performance and safety of shipping.

To achieve these overall goals, the author's prior work in her Licentiate thesis and its appended papers, Costa (2016), investigated based on end-users' perceptions and a literature review (a) the benefits (from an individual to a societal level) that would result from a human-centred and participatory approach to the design of ships and ship systems, as well as (b) the perceived success factors for involving the end-users and achieving said benefits. By investigating these questions, a better understanding of the users, their common priorities and needs was gained, which is a fundamental step in designing for them (Langford & McDonagh, 2003). How the end-users perceived they could contribute to design was also featured. Finally, how the success factors could be accommodated and HCD adopted for the shipping industry to achieve the benefits was proposed.

The ultimate perceived benefit of a participatory approach to design was overall maritime safety, being this the critical goal that naval architects and ship systems designers should design for. To fulfil this, the design process should involve the crew and facilitate stakeholder communication for requirement elicitation and negotiation during design, rule making and purchasing. It was suggested that the

consideration of E/HF issues should not only occur when designing for human-technology interaction, physical layouts and hazard avoidance, but also when designing and standardizing safety routines, training, and devising regulations. Based on the empirical results of the appended articles and a review of literature, the benefits of and prerequisites for successful HCD integration within shipping suggested a holistic model for maritime HCD.

The Licentiate thesis helped to expand the knowledge of what is important in maritime design and operations, and assembled E/HF recommendations for naval architects and ship systems designers, ship owners and regulatory bodies. This work intended thus to serve as a starting point and a complement to further and more specific user and context-of-use research within specific design projects.

1.2 Overall Research Scope, Aims and Delimitations

The present thesis gives continuation to the research work described above with the support of six peer-reviewed papers found in full within the appendix of this thesis. The aim of this thesis is to emphasize the success factors (input) for and benefits (output) of a participatory approach to the general design of ship systems, and in contrast assess design and development project barriers and challenges in user involvement and in HCD practice and how E/HF principles can be introduced to address these process gaps. Based on a human-centred approach, fieldwork, interviews and a usability test of a novel e-Navigation tool were also performed aimed at understanding maritime operations and information technology, and gather user feedback for direction and further development of the e-Navigation programme (IMO, 2014c) to assist decision making and enhance communication between navigators and shore-based operators. This research to understand current standard practices and technologies helped to appreciate some of the ongoing challenges in the e-Navigation programme from a systems perspective, and to focus the message of this thesis on the value of E/HF in this transition.

The conclusions drawn from this research pertain mainly to marine structures and technologies of commercial vessels. Although the content may be applied across other vessel types or even other contexts, it was not the main focus of this thesis nor of the appended articles.

The Human Element resolution and the e-Navigation programme laid out by the IMO are of relevance in this thesis due to their global impact in the maritime domain. The HCD model and principles issued by the International Organization for Standardization (ISO) are especially considered although other HCD models exist (e.g., IDEO.org, 2015; LUMA Institute, 2012).

This thesis and appended articles have counted on the participation of, and hence focused on, maritime operators (mainly bridge officers, VTSOs, and pilots) and design teams of maritime-related software. Nonetheless, the recommendations and directions for future research are directed at the whole range of maritime stakeholders and multidisciplinary teams in the domain that affect or are affected by design. This includes ship owners, rule makers, educators, researchers and practitioners.

1.2.1 Research Questions

Stemming from the compilation of appended papers, this thesis focuses on the following research questions:

- [1] What are the perceived success factors (input) for and the benefits (output) of a participatory approach to the design of ship systems?

- [2] What are management and user involvement barriers that may contribute to project delays and user resistance, and how can they be overcome based on a participatory, sociotechnical approach?
- [3] What are characteristics and challenges of HCD practice and how can HCD be introduced in future projects?
- [4] What are the gaps and opportunities that could influence the future directions of e-Navigation, and how can this affect the transport system as a whole?

1.2.2 Summary of Appended Articles

Specifically, the appended articles make up and contribute to the research questions in this thesis, as per the following:

Article I	Costa, N., de Vries, L., Dahlman, J., & MacKinnon, S. (2015). Perceived success factors of participatory ergonomics in ship design. <i>Occupational Ergonomics</i> , 12(4), 141-150. doi:10.3233/OER-150230
Research Question:	[1] What are the success factors (input) for the practice of a participatory approach to the design of ships and ship systems, and what are the benefits (output) that can result from it?
Summary:	The aim of this focus group study was to investigate the perceptions of novice seafarers about the success factors for (input) and benefits of (output) end-user participation in the design of ships and ship systems. The results yielded a conditional/consequential matrix of prerequisites and subsequent benefits at a micro and macro levels, ultimately perceived to promote efficiency and safety at sea.
Contribution to Thesis:	Identifying the benefits and prerequisites for the practice of end-user involvement in the design of ships and ship systems from the perceptions of novice seafarers.
Article II	Costa, N. A., Vesting, F., Dahlman, J., & MacKinnon, S. (2019). A case study of user adherence and software project performance barriers from a sociotechnical viewpoint. In T. Ahram (Ed.), <i>Advances in Artificial Intelligence, Software and Systems Engineering. AHFE 2018. Advances in Intelligent Systems and Computing</i> (Vol. 787, pp. 12-23): Springer, Cham.
Research Questions:	[1] How were the university-company collaboration project and user involvement organized? [2] What were the main management barriers and why might they have occurred? [3] How can taking a sociotechnical, participatory, human-centred approach to development be helpful in the management of such project risks?
Summary:	The aim of this case study was to document a university-company project optimizing an existing marine propeller design software in terms of management and end-user involvement. It discussed how the project and user involvement were organized, identified management barriers and

discussed why they may have occurred on the basis of a sociotechnical and participatory perspective to organizational change. The data were based on a qualitative research approach with semi-structured interviews and direct observations with university and company stakeholders throughout thirteen months. The results suggested that there was lack of a planned strategy for deliverables or resource use in the project; the users exhibited low adherence towards the new software version, as well as there was limited time and training allocated for them to test the optimized software. Lessons learned suggested a need for more support from the management in clarifying stakeholder roles and contributions, including structured and consistent ties with the users engaging them earlier and beyond testing the software for malfunctions, to enhance knowledge mobilization, involve them in the change and increase acceptance.

Contribution to Thesis: Pointing at potential user involvement and management barriers and suggesting based on a literature review how a sociotechnical and participatory approach to development, testing and implementation can be of value in software projects to mitigate the identified risks.

Article III Costa, N. A., Holder, E., & MacKinnon, S. N. (2017). Implementing human centred design in the context of a graphical user interface redesign for ship manoeuvring. *International Journal of Human-Computer Studies*, 100(2017), 55-65. doi:10.1016/j.ijhcs.2016.12.006

Research Questions:

- [1] What was the uptake of E/HF methods by the HCD-novice team and what was it affected by?
- [2] What were the challenges and perceived benefits of HCD in context?
- [3] What may the most effective ways to introduce and use HCD in firms in the maritime sector inexperienced in the approach be?

Summary: The aim of this case study was to investigate a case of human-centred redesign of a bridge wing interface for ship manoeuvring by a team of engineers from a maritime consultancy firm that did not have HCD as regular or standardized practice. It explored how HCD was interpreted and utilized and how HCD benefits could be achieved. The findings were summarized and discussed from the perspective of the team's uptake of HCD advice by external E/HF specialists and literature in the subject; how HCD was learned and practiced, its challenges, benefits, and most effective ways to introduce and use HCD in firms in the maritime sector inexperienced in the approach. To document the process, direct observations, collective interviews and focus groups at regular intervals, augmented with reports and a questionnaire completed by the design team, were performed. The conclusions highlighted issues defining the team members' roles and transferring knowledge between them, and the impact of the industrial context and constraints on the application of HCD, as well as of who applies it, of how it is depicted in literature and perceived by HCD-novice teams. Such aspects had an impact on the team's chosen methods during the process and how the redesign of the interface progressed. HCD proved to be context-

dependent, and where and how its barriers occurred may be key knowledge for further development and adoption of E/HF methods.

Contribution to Thesis: Identifying potential challenges of and effective paths into HCD practice in HCD-novice organizations.

Article IV

Costa, N. A., Lundh, M., & MacKinnon, S. N. (2018). Identifying gaps, opportunities and user needs for future e-navigation technology and information exchange. In N. Stanton (Ed.), *Advances in Human Aspects of Transportation. AHFE 2017. Advances in Intelligent Systems and Computing* (Vol. 597, pp. 157-169): Springer, Cham.

Research Questions: [1] What are the current typical operations and communication channels of VTS operators (VTSOs), pilots and bridge navigators in maintaining safety of navigation (anti-collision and anti-grounding)?

[2] How are these operations mediated by current e-Navigation technology and what are the gaps and overlaps that need improvement?

Summary: The aim of this study was to investigate the current maritime network, typical work practices and technologies to identify current e-Navigation technology gaps and potential development opportunities. This was done through qualitative research with a Vessel Traffic Service (VTS)¹ centre, coastal pilots and navigation instructors. An important gap was the compartmentalization of relevant information, requiring many sources and communication channels to gather round all relevant parameters/details. Another gap was the disparity in accessibility of information for the different stakeholders. Basic information such as a vessel's draught was shared repeatedly among different stakeholders and was often ambivalent or contradictory. Potential was demonstrated to make sources more reliable and information more integrated, to improve efficiency and reduce uncertainty and repetitions via the very high frequency (VHF) radio.

Contribution to Thesis: Describing gaps and opportunities of current user operations, as well as the impact of further development of e-Navigation technologies.

Article V

Costa, N. A., Lundh, M., & MacKinnon, S. N. (2018). Non-technical communication factors at the Vessel Traffic Services. *Cognition, Technology & Work*, 20(1), 63-72. doi:10.1007/s10111-017-0448-9

Research Question: [1] What were the non-technological aspects in VTSOs' communications with ships and other shore operators that played a role in decision making and assistance of vessels in maintaining safe passage in their area?

Summary: The aim of this study was to describe the non-technological aspects of everyday communications and operations in receiving and transmitting local

¹ The VTS is a shore-based organization that monitors and helps coordinate vessels around port areas, providing updated local information.

information at the VTS to assist passing vessels in maintaining efficiency and safety. The study discussed how these aspects reflect challenges in the role of the VTS and influence the VTSOs' judgements, expectations and decision making in remote assistance. Among the findings, it was observed that VTSOs coped with the limitation of being geographically separated from the vessels they were assisting by taking advantage of the available technologies and VHF radio communications to make judgements and safety decisions on which of the vessels to prioritize in terms of how much assistance to provide or how much trust to bestow. The VTSOs also felt limited as to the assistance that could be provided, in terms of how much or how little power the VTSOs felt they could exercise over the vessels stemming from the ambiguity of the description of the VTS role of different centres, as well as in terms of the perceived unreceptiveness of the ship bridge crews.

Contribution to Thesis: Describing the non-technological aspects in VTSOs' communications with ships and other shore operators that play a role in decision making and assistance of vessels, and that should be taken into consideration in further developments of VTS service provision and training, in rethinking certain regulations, as well as in further developments of e-Navigation technologies.

Article VI Costa, N. A., Jakobsen, J. J., Weber, R., Lundh, M., & MacKinnon, S. N. (under review). Assessing a maritime service website prototype in a ship bridge simulator: Navigators' experiences and perceptions of novel e-navigation solutions. *Manuscript submitted for publication in WMU Journal of Maritime Affairs*.

Research Questions:

- [1] How are existing technologies utilized for information gathering to make decisions regarding voyage planning and navigation, and what are the gaps and challenges in these activities?
- [2] Compared to standard practices and systems, are the functions of the new website prototype accepted and do they aid the navigators in a significant way that existing technologies fail to do and how?
- [3] What are the lessons learned and what direction should the new website or e-Navigation in general take in order to address existing gaps?

Summary: The aim of this quasi-experimental study was to evaluate with mariners a novel maritime service website prototype (BalticWeb) for proof of concept and usability in a ship bridge simulator. The prototype was meant as an aid to existing systems and methodologies for voyage planning and navigation and included four services: standardized VTS reporting, real-time maritime safety information (MSI) promulgation directly on the charts, fuel-saving-based route optimization, and no-go area contours based on vessel draught and hydrographical weather data. The study began with five days of trials focused on today's standard practices, which served as a baseline to compare to subsequent four days of trials testing the prototype. The results showed that there are gaps in the current technologies that may be improved by the tested services (especially during voyage planning), but that they would be most beneficial if integrated and approved by the International Maritime

Organization (IMO) as part of the existing systems rather than to add yet another source and tool to an already complex environment. Further development should account for all involved stakeholders, modified work tasks, regulations and standards, as well as training and re-skilling.

Contribution to Thesis: Testing a novel e-Navigation tool for proof of concept and usability, user uptake and acceptance and providing direction to further e-Navigation developments to address existing gaps, user needs and systems goals.

Nicole A. Costa is the first and main author of all appended articles, developed with the support of the co-authors through a series of iterations.

1.3 Thesis Structure

This thesis consists of seven sections and an appendix containing the six articles that make up the content of this thesis. Section 1 provides a general introduction of the research problems under investigation in this thesis in the context of the shipping industry; the scope, aims and delimitations of this research; research questions; and a summary of the appended articles. Section 2 describes in more detail the maritime context and concepts in which the research was performed. Section 3 presents the theoretical framework that the data collections and analyses were based upon. Section 4 lists the research approach, procedures, data collection and analysis methods used in each study. Section 5 reports the selected key findings from each of the six appended articles. Section 6 presents an overarching reflection across articles, their contributions and recommended directions for the domain. Finally, section 7 recapitulates and emphasizes the main messages of this thesis.

2 Context

2.1 The Merchant Shipping Industry

Global merchant shipping is characterized by all the structures, operations and people that relate to all maritime-related activities through water, such as the transport of cargo and passengers (Lützhöft, Grech, & Porathe, 2011; Mallam, 2016) and all other activity areas required to support it (Lützhöft et al., 2011). This industry is the means via which 80-90% of all world trade is performed today (International Chamber of Shipping, 2017; United Nations Conference on Trade and Development, 2017). The world merchant fleet includes general cargo ships, container ships, oil and chemical tankers, dry bulk carriers, combined carriers, ferries and cruise ships, gas carriers, offshore supply ships, specialized ships, tugs, dredgers (Stopford, 2009). In early 2017, the world fleet consisted of 93,161 vessels, with a combined tonnage capacity of 1.86 billion dead-weight tons (dwt), worth 829 billion dollars. Total volumes of cargo amounted to 10.3 billion tons in 2016, and in 2015 it was estimated that over 1.6 million seafarers were employed worldwide in maritime operation roles (United Nations Conference on Trade and Development, 2017).

To maintain competitiveness, ship owners have had a continuous concern for the reduction of operational costs by reduced manning levels (Lützhöft et al., 2011), minimization of accidents, and the introduction of modern and complex technology for improved propulsion, fuel savings, hull design, enhanced manoeuvrability and cargo-handling systems (Costa & Lützhöft, 2014; Lützhöft & Vu, 2018; Pomeroy, 2003; The Nautical Institute, 1998). Currently, the domain is undergoing the increased demand and challenge for emission reduction, more information and interconnectivity between ships and shore for the purpose of safety, efficiency and environmental protection (de Vries, 2015), and suffering a transition driven by the new technological revolution (Man et al., 2018a).

The maritime work environment is complex and safety-critical (Conceição, Dahlman, & Navarro, 2017; Costa, 2016; de Vries, 2015; Grech et al., 2008; IMO, 2018; Lützhöft et al., 2011; Lützhöft & Vu, 2018; Mallam, 2016; Manuel, 2011; Praetorius, 2014) and accidents can have disastrous consequences (Hetherington, Flin, & Mearns, 2006), even if shipping is generally considered a safe and economical alternative for commercial transport (Chauvin, Lardjane, Morel, Clostermann, & Langard, 2013). It is also a unique industry (Costa, 2016; Lützhöft et al., 2011; Mallam, 2016; Manuel, 2011; Österman, 2012) of isolated and harsh work environments for prolonged periods of time, distributed stakeholders, hierarchical structures, multicultural crews, and limited team-based training (Lützhöft et al., 2011; Manuel, 2011). Each ship is its own principal decision maker and is responsible for maintaining own safe and efficient operations (Praetorius, 2014). These operations are dependent on the joint work of the shipboard individuals through the use of information and decision-making technology, and aided by shore-based assistance (de Vries, 2015; Praetorius, 2014).

There has been extensive regulatory focus on safety, major improvements to ship construction and practices, and the number of accidents has continuously dropped over the twentieth and twenty-first centuries, having declined 50% in the past ten years (Allianz Global Corporate & Specialty, 2017; Chauvin et al., 2013; Manuel, 2011; Roberts, Nielsen, Kotłowski, & Jaremin, 2014) with the support of advanced technology (Allianz Global Corporate & Specialty, 2017; Hetherington et al., 2006). Yet, accidents continue to occur (Allianz Global Corporate & Specialty, 2017; Chauvin et al., 2013; CyClaDes, 2015; Earthy & Sherwood Jones, 2010; European Maritime Safety Agency, 2017; Kataria, Praetorius, Schröder-Hinrichs, & Baldauf, 2015; Lurås, 2016) with collisions and groundings being two of the main types of shipping losses in European waters (Chauvin et al., 2013). Occupational mortality and morbidity rates for seafarers remain among the highest of all occupations in western society (Roberts,

2008; Roberts & Marlow, 2005; Roberts et al., 2014). During 2016, 3,145 casualties and incidents, 106 fatalities, 957 people injured and 26 ships lost were reported by the European Maritime Safety Agency (2017), and 2,611 casualties and 85 losses were reported by Allianz Global Corporate & Specialty (2017). Seeing this, there is still work to be done to make this industry safer to work in.

2.2 The Human Element

In 1997, the IMO initiated and adopted resolution A.850(20), *The Human Element* (IMO, 2003), dedicated to promoting the safety of life and work at sea and environmental protection. The human element is defined as “a complex multi-dimensional issue that affects maritime safety and marine environmental protection” involving “the entire spectrum of human activities performed by ships’ crews, shore based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to cooperate to address human element issues effectively” (IMO, 2003). In this definition, the joint activities and the concerted efforts of all maritime stakeholders towards the consideration of E/HF aspects are recognized. Within this resolution, the IMO established principles for the promotion of a safety culture and seafarer professionalism (e.g., on safe manning, fatigue, working groups, work and rest hours, and formal safety assessments). Some of the operational codes and conventions to address human element principles are the International Convention for the Safety of Life at Sea (SOLAS) and its International Safety Management (ISM) code (IMO, 1974), and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Manila) (IMO, 2010). The Convention on the International Regulations for Preventing Collisions at Sea (COLREGs)² (IMO, 1972), the International Convention for the Prevention of Pollution from Ships (MARPOL) (IMO, 1973), and the International Convention on Maritime Search and Rescue (SAR) (IMO, 2004) also have human element implications.

The human element has increasingly received attention (Manuel, 2011), especially with growing operational complexity (Conceição et al., 2017), as between 75-96% (Allianz Global Corporate & Specialty, 2017; Hanzu-Pazara, Barsan, Arsenie, Chiotoroiu, & Raicu, 2008; Veysey, 2013) of maritime accidents have been attributed to ‘human error’ (Hetherington et al., 2006; Lochner, Duenser, Lützhöft, Brooks, & Rozado, 2018; Lurås, 2016; Lützhöft et al., 2011). Among the E/HF issues that have been identified to cause maritime accidents are human decision and perception errors linked to uncertainties in communication (Allianz Global Corporate & Specialty, 2017; Chauvin et al., 2013) and lack of information exchange, loss of situational awareness and shared mental models, misuse of instruments, knowledge limitations, co-existence of official regulations and unwritten local norms, use of the wrong publications in passage planning (Chauvin et al., 2013), flawed perception of risk and inadequate training (Roberts et al., 2014), and high mental workload (Hetherington et al., 2006; Lochner et al., 2018). Concurrently, one-third of all maritime accidents have been linked to poor design (Grech et al., 2008), and two-thirds of 129 maritime casualties analysed in a study by Kataria et al. (2015) were linked to human-machine interaction and automation issues due to poor design. This draws attention to the need for E/HF considerations in design in the maritime industry.

The implementation and practice of E/HF approaches has remained limited and slow in the maritime domain (Lützhöft et al., 2011). This is believed to be due to the predominance of the engineering sciences in the industry, and to hesitancy towards cultural change and investment in the social

² COLREGs refer to anti-collision regulations (IMO 1972). This works similarly to road driving regulations in marking the waterways where ships are recommended to navigate. Ships going in opposite directions will then be separated by a line marked on the sea charts.

sciences, making the conveyance of a usability mindset difficult (Lützhöft & Vu, 2018; Petersen, 2012). Arranging representative user groups and field sites can also be a logistic challenge in this domain (Lurås, 2016; Österman, Berlin, & Bligård, 2011). Furthermore, maritime authorities and regulatory bodies propose regulations often as a direct response to maritime accidents, and a more systemic and proactive approach to addressing the human element seems to rarely happen (Lützhöft et al., 2011; Schröder-Hinrichs, Hollnagel, Baldauf, Hofmann, & Kataria, 2013). Their compliance is generally voluntary, explained prescriptively and at a high-level, failing to provide sufficient guidance on how to incorporate such knowledge into the design of merchant vessels, and thereby proving difficult for operational compliance (Kataria et al., 2015; Rumawas, 2016). The more automation and technological complexity is introduced into the domain though, the more the human element should be brought into focus (Conceição et al., 2017), as is evidenced by the human-centred focus of current programmes such as e-Navigation (IMO, 2014c).

2.3 e-Navigation

The e-Navigation programme is defined as “the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment” (IMO, 2014b, 2014c). An example of existing digitalization onboard is the electronic chart display and information systems (ECDIS), which made possible replacing the traditional paper charts with electronic navigation charts (ENC) (Graff, 2009) and displaying voyages and traffic on screens with real-time information, on ships and shore-based centres. Work has been published on the e-Navigation concept, understanding operations, developing and testing new technologies (Amato, Fiorini, Gallone, & Golino, 2011; Baldauf, Benedict, Fischer, Gluch, Kirchhoff, Klaes, Schröder-Hinrichs, Meißner, Fielitz, & Wilske, 2011; Hahn, 2014; Jonas & Oltmann, 2013; Kim, Jeong, & Park, 2014; Lee, Wang, & Huang, 2015; Motz, Dalinger, Höckel, & Mann, 2011; Motz, Widdel, Oei, MacKinnon, & Alexander, 2004; Patraiko, 2007; Patraiko, Wake, & Weintrit, 2010; Rødseth, 2011; Weintrit, 2011; Weintrit, Wawruch, Specht, Gucma, & Pietrzykowski, 2007), including the innovative concept of unmanned vessels and how it is proposed to contribute to e-Navigation principles/goals (Burmeister, Bruhn, Rødseth, & Porathe, 2014). The S-Mode proposed by the Nautical Institute has also been long discussed as a contributing solution, as a function to remove personalized ECDIS settings and bring the mariner back to a default display and features mode with the click of a button (Bhardwaj, 2013; Graff, 2009; Grech & Lützhöft, 2016; Patraiko, 2007; Patraiko et al., 2010), which could become increasingly important as manufacturing variability and complexity increases.

An implementation strategy which identified five prioritized e-Navigation solutions was approved to be accomplished by 2019 (IMO, 2014a). The prioritized solutions include improved, harmonized and user-friendly bridge design; improved reliability, resilience and integrity of bridge equipment and navigation information; integration and presentation of available information in graphical displays received via communication equipment; means for standardized and automated reporting; and improved Communication of VTS Service Portfolio (not limited to VTS stations). Within the e-Navigation implementation plan, guidelines were devised on Software Quality Assurance (SQA), HCD and Usability Testing (UT) (IMO, 2005, 2015a, 2015b) for the implementation of a holistic approach to e-Navigation systems design (IMO, 2014a). Additionally, an online platform with guidelines to the HCD framework began being developed within the European union’s CyClaDes project by the classification society DNV-GL and international partners to incentivize and support marine designers and other maritime stakeholders to consider E/HF (van der Merwe, 2015). Research has also investigated general HCD integration in the design of ships and ship systems (Costa, 2016; Costa & Lützhöft, 2014; Rumawas, 2016; The Nautical Institute, 2015; Österman, 2012), and particularly into the general model

of ship design by Evans (1959) (de Vries, Costa, Hogström, & Mallam, 2015; de Vries, Hogström, Costa, & Mallam, 2017), into general arrangement and ship workspaces (Mallam, 2016; Mallam, Lundh, & MacKinnon, 2015; Mallam et al., 2017) such as the engine department (Mallam, 2014) and the ship's bridge (Bligård, Österman, & Berlin, 2014; Lurås, 2016; Österman, Berlin, & Bligård, 2016), and into passage navigation technology (Man, Lützhöft, Costa, Lundh, & MacKinnon, 2018b).

3 Theoretical Framework

3.1 Ergonomics and Human Factors

Concerns with the interactions between people and their work environments date back to Ancient Greece (Wilson, 2000). The term *Ergonomics*, from the Greek *ergo* (work) and *nomos* (natural law), defined as the applied science of work, was then introduced in 1857 by the Polish scientist Wojciech B. Jastrzębowski in his work <<An outline of ergonomics, or the science of work based upon the truths drawn from the Science of Nature>> (Jastrzębowski, 1857, reprinted in 2006). In 1949, the term was espoused by the British chemist and psychologist Kenneth Frank Hywel Murrell at an Admiralty meeting, which led to the formation of the first Ergonomics Research Society soon after. This happened mostly as a result of the scientist's military studies during and post-World War II, recognizing the growing technological complexity and the increased physical and cognitive demand on the human operator for increased performance (Chartered Institute of Ergonomics & Human Factors, 2017). In the USA, the term *Human Factors* emerged within the same context and with a similar meaning as Ergonomics (Chartered Institute of Ergonomics & Human Factors, 2017; Helander, 1997). Ergonomics was expanding in Germany, the Netherlands and Scandinavia from medicine and anatomy, and from industrial engineering in Eastern Europe (Wilson, 2000). Although officially the terms *ergonomics* and *human factors* often appear together and are treated synonymously (Dul, Bruder, Buckle, Carayon, Falzon, Marras, Wilson, & van der Doelen, 2012; IEA, 2018), in popular practice there has been a tendency to differentiate and attribute *ergonomics* to the physical aspects of design of human work, and *human factors* to those more cognitive and organizational aspects (Chartered Institute of Ergonomics & Human Factors, 2017; Helander, 1997; Koskinen, Zimmerman, Binder, Redström, & Wensveen, 2011).

The International Ergonomics Association (IEA) defines ergonomics and human factors as “the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance”, and that “helps harmonize things that interact with people in terms of people's needs, abilities and limitations” (IEA, 2018) (see also Wilson, 2000). The IEA (2018) also designates different domains of focus within the discipline, namely physical ergonomics (anthropometry, physiology), cognitive ergonomics (perception, memory, mental workload, decision making, performance), organizational ergonomics (structures, teamwork, policies, communication, management), among others. This definition brings five inherent characteristics to light: 1) ergonomics and human factors is an applied and design-oriented discipline; 2) it is driven by human/user needs; 3) it is concerned with the human at all levels of interaction (physical, psychological, social) with its environment (physical, social, informational, organizational) from the perspective of using a tool and performing a task (micro), to being part of a work system or unit (meso), or even part of a larger network of units (macro); 4) it is holistic and accounts for the sociotechnical systems perspective, hence the context is considered regardless of system boundaries; and 5) it is not limited to work settings but covers all range of human activity (see also Dul et al., 2012).

3.2 Sociotechnical Systems Perspective

Systems are defined as sets of interdependent elements and exist within an environment (Dul et al., 2012; Skyttner, 2005). Within systems theories, a sociotechnical system can be defined as a system of a complex nature where social and technical elements co-exist and interact, oriented towards a common goal (Hendrick & Kleiner, 2001; Vicente, 2006). E/HF is intrinsically a systems- and particularly a sociotechnical systems-oriented discipline in the sense that it examines the interactions between

humans and other elements of the system, and focuses on designing the system to fit the human and the system's goals better (Dul et al., 2012; Hendrick & Kleiner, 2001; IEA, 2018; Vicente, 2006; Wilson, 2014). In other words, elements are not evaluated in an isolated manner, because their relationships and emergent properties, the complexities and what makes up the system, would be lost (Vicente, 2006).

Systems do not define themselves; they are an abstraction that must be recognized and defined by the observer (Skyttner, 2005). Hence, when defining a problem to inspect and solve, the boundaries of that problem need to be delimited to the aspects of the humans (physical, psychological, social) and of the environment (physical, social, informational, organizational) – at a micro-, meso- or macro-level – that are of relevance for the study or intervention. Here, to assume the holistic and systemic perspective, the relationship among the human, the tool and the task should be investigated, as well as the context in which this subsystem exists (Dul et al., 2012; Skyttner, 2005). Studying a subsystem from one point of view is complementary to other points of view or other subsystems within the larger system, and all occurs within the umbrella of the multidisciplinary E/HF field.

Similarly to Dul et al.'s (2012) sociotechnical systems description, Vicente (2006) also proposed how knowledge about people can be organized into different levels: the physical, the psychological, the team, the organizational and the political. The *physical* level is about the physical capabilities and limitations of the target user groups of a specific design, with regards to their physiology, anthropometrics and kinetics. The *psychological* or cognitive level corresponds to memory, logic and expectations. The *team* level refers to two or more people working together towards a common goal, where coordination, communication and effectiveness are important aspects in design. The *organizational level* is associated with staff, culture, leadership, reward systems, schedules, performance, information and knowledge flow. The *political* and cultural level is at the top, determining whether specific designs on the market survive and succeed.

According to the macroergonomics model of work system design by Hendrick and Kleiner (2001), the technology and the personnel subsystems are linked by routines, organizational structures and processes, and beyond the boundaries of this system is an external environment in which the system exists, upon which it depends and to which it must adapt. Optimizing the work system, then, means examining the technical subsystem, the social characteristics of the personnel subsystem, the organizational and management structures (formal and informal), the physical and cultural features of the internal work environment, and the external environment in terms of culture, politics, economics, education and technology, and how they all interact as a unit (Haro & Kleiner, 2008; Hendrick & Kleiner, 2001). These different authors, then, present the common sociotechnical systems notion that the social and technical elements within a given environment are interdependent and its consideration determines the success of a design and vice-versa.

The shipping industry is itself recognized as a dynamic and complex sociotechnical system (Conceição et al., 2017; Costa, 2016; Grech et al., 2008) where each ship is its own sociotechnical subsystem of social and technical elements onboard, and each ship is then part of a larger network of ships, shore structures and authority bodies, on a global level. In this context, a sociotechnical model labelled “The Septigon Model” was conceptualised by Grech et al. (2008) specifically to suit the maritime domain, depicting that system performance and the achievement of mutual system goals are determined by the interactions between the individual, the technology, the practice, the group, the physical and organizational environments, society and culture. The *individual* level refers to the human in the system and its physical and psychological limitations. The *group* level refers to team management and communication. *Technology* is in turn associated with hardware and software tools, instruction manuals and symbolism. Whereas *practice* is about the informal norms and customs, the

organizational environment is about the organizational culture, the formal rules, the official procedures and policies. The *physical environment* includes aspects of spatial organization and display, weather, motion, temperature, lighting, visibility, noise and vibration. Finally, *society* represents the cultural, socio-political and -economic context where the organization exists. Once again, overlooking one of these nodes in design might disrupt the mechanisms of the system and the system goals.

3.2.1 Organizational Change through Technology

Change in an organization can be prompted by the introduction of a new technology (Arroyabe, Arranz, & Arroyabe, 2015; Leavitt, 1965; Schein, 2010) or the further exploitation of an existing company technology (Arroyabe et al., 2015) (see also Long and Spurlock, 2008). Organizations have been described as complex systems with four co-dependent variables: actors, technology, tasks and structures (Leavitt, 1965), where change in one variable will affect the others. Based on this model, Lyytinen, Mathiassen, and Ropponen (1996) warned that software development risks can occur when the variables are in conflicting states and harm the stability of the system (see also Leavitt, 1965). This can range from limited resources, information or skills necessary for the developers to assess the users and their environment as to how the software can be used and implemented, and to make design decisions; to the managers' lack of attention or knowledge regarding available information necessary to the success of the development process. In turn, this can lead to project delays or cancellations, to implementation processes exceeding the budget, to the users not knowing how to use or not accepting the software (Lyytinen et al., 1996), to inadequate software performance and requiring significant and expensive programming adjustments after implementation (Lyytinen et al., 1996; Tait & Vessey, 1988). To avoid such risks, Lyytinen et al. (1996) suggested assembling information about the three environments in which the software development takes place: the system/use environment where the software is to be operated; the development environment where the software is developed; and the management environment that determines how the software development management occurs, what the system requirements are, how it's purchased, implemented and used. In this process, there must be a feedback loop between environments to accentuate teamwork and user involvement, share knowledge and improve practices (Lyytinen et al., 1996). Frequent interactions and strong ties, joint and participatory problem-solving, can help ensure knowledge transfer (Arroyabe et al., 2015), clarify the goals of all parties, avoid equivocality (Arroyabe et al., 2015; Sjödin, Frishammar, & Eriksson, 2016), predict risks, prepare the organization for the change and reduce resistance (Lyytinen et al., 1996; Schein, 2010).

Lyytinen et al. (1996)'s risk-based approach can then be compared to a triangular activity model (Andersson, Bligård, Osvalder, Rissanen, & Tripathi, 2011) suggesting that the developers (actors) will use design and development methods (means) to create a software tool (end), which will in turn be the means for the users to achieve their own end-goals. I.e., one person's work outcome becomes another person's work tool necessary to complete work tasks that will subsequently help to maximize company success. Hence, not inquiring the use environment of the software can result in essential information being missed (Lyytinen et al., 1996; Parent, Roy, & St-Jacques, 2007; Sjödin et al., 2016), risks unpredicted (Lyytinen et al., 1996), and the performance of the technology-personnel work system suboptimized (Hendrick & Kleiner, 2001).

3.3 User-Oriented Design Approaches

Design has been increasingly considered in the light of user needs over the past seven decades (Sanders & Stappers, 2008). For the integration of E/HF principles, methods, techniques and knowledge in design practice, a number of user-oriented approaches and philosophies have been reported. Namely, there is human-/user-centred design (ISO, 2010; Maguire, 2001; Williams, 2009),

participatory design/ergonomics (Barcellini, Prost, & Cerf, 2015; Haines, Wilson, Vink, & Koningsveld, 2002; Langford, Wilson, & Haines, 2003; Vink, Koningsveld, & Molenbroek, 2006), co-design (Barcellini et al., 2015; Sanders & Stappers, 2008), usability engineering, empathic design, design for user experience (UX), emotional design (Giacomin, 2014), design thinking (Brown, 2008), user-centred systems design (Gulliksen, Göransson, Boivie, Blomkvist, Persson, & Cajander, 2003), human-centred systems design (Gill, 1996), activity-centred design (ACD) (Bligård, Simonsen, & Berlin, 2016; Williams, 2009), goal-directed design (Williams, 2009), systemic design (Lurås, 2016). The consideration for the end-user is a common trait among these approaches, and in many of them end-user participation or collaboration is a prerequisite, meaning that the end-user is brought into the design process to become involved and provide input. In fact, experts have argued that in order to practice good ergonomics (Wilson, 2014), truly account for user needs (Langford et al., 2003; Sanders & Stappers, 2008), and analyse and design work systems (Andersen & Broberg, 2017; Hendrick & Kleiner, 2001), design must be participatory. Much of the E/HF practice has unavoidably been participatory to some extent (Haines et al., 2002).

Research about user participation (Sanders & Stappers, 2008) and the emergence of participatory approaches (Gill, 1996) date back to the 1970s with the Scandinavian Collective Resource Approach to amplify the value of industrial production by involving workers in the design and development of new work systems (Gill, 1996; Kraft & Bansler, 1992; Sanders & Stappers, 2008) and of computer automation (Steen, 2011); the German humanization of work programme (Kissler & Sattel, 1982) and the British Lucas Plan of socially useful production and technology (Smith, 2014). In the early 1980s, the focus on user participation rose within the E/HF community (Langford et al., 2003).

Participation can take many forms depending on the design approach, on what is being designed and for whom it is being designed, on who is designing it, the available expertise and the company's policies, culture and business models, and on design trends. For example, design projects following an E/HF mindset should have multidisciplinary teams that include E/HF specialists working alongside the designers, developers and other professionals (Costa, 2016; Dul et al., 2012; Grech et al., 2008; ISO, 2002; Man et al., 2018b). User involvement can be direct or indirect (via representatives); active, meaning the users can influence design ideation and conceptualization collectively with the designers and other stakeholder groups (Sanders & Stappers, 2008), or passive, meaning the users are given instructed tasks or asked to comment on design concepts developed by others (Sanders & Stappers, 2008); and take place at different stages of the design process (Haines et al., 2002; Langford et al., 2003).

Participatory approaches to design establish a collaboration with users and stakeholder groups affected by the change to facilitate the collection and interpretation of pertinent expert knowledge relating to identifying aspects of their workplace, systems or tools that can be improved (Andersen & Broberg, 2017; Glina, Cardoso, Isosaki, & Rocha, 2011), developing improved design ideas and solutions for problems, and supporting the development and implementation of such solutions (Glina et al., 2011; Haines et al., 2002). The more complex the problem-solving, the more the relevant stakeholder groups should engage in the knowledge creation (Andersen & Broberg, 2017) and transfer process to fulfil the capacities required (generative, disseminative, absorptive, and adaptive/responsive) to successfully solve the problem (Parent et al., 2007). Active user participation has been incentivized early and continuously throughout design projects (Grech & Lützhöft, 2016; Gulliksen et al., 2003; ISO, 2010; Olsson, 2004) to empower users to influence design ideation and conceptualization of their workstations and tools (Sanders & Stappers, 2008; Vink et al., 2006).

The potential of E/HF has had limited exploitation in practice. Dul et al. (2012) identified that 1) stakeholders involved in design, management and use are unaware of the potential of this discipline;

2) in industries or projects where there is demand for the discipline, such as the safety-critical industry of transport, high-quality E/HF in design processes is scarce; 3) the E/HF field is small and can hence become overlooked; and 4) the multidisciplinary trait of the discipline can be a drawback in that it fails to convey a single and concrete message to those outside of it. Dul and Neumann (2009) also identified that E/HF is usually implemented too late in design projects more as a reaction to health and safety issues than proactively within the company strategy, meaning that ergonomic corrections to the design become costlier by that time and hence E/HF becomes perceived by the designers and managers as an inefficient and resource-consuming activity. Also, it was argued that there is a lack of education about E/HF in engineering (Broberg, 2007) and lack of targeted E/HF publications in business and management mediums directed at the change makers (designers, managers) (Dul & Neumann, 2009). Hence, it was recommended that the E/HF community should strengthen and present the full E/HF value proposition to them (Dul & Neumann, 2009).

The use of participatory approaches by practitioners has also remained limited (Gulliksen et al., 2003; Olsson, 2004). It has been argued that defining a user population may imply difficulties (Olsson, 2004) and user participation imply more resources than, for instance, analytical usability evaluations (e.g., heuristics) which do not require users as test subjects (Bligård & Osvalder, 2013; Nielsen & Mack, 1994); produce uncertainty stemming from communication gaps and lack of consensus between stakeholders (Mallam, 2014), difficulties from the users in communicating needs and from the designers and engineers in assimilating the user input into the design (Bligård et al., 2014; Kujala, Kauppinen, & Rekola, 2001) or fulfilling the needs of the different user groups simultaneously (Olsson, 2004); cause additional workload to the team (Brodbeck, 2001) and be time-consuming (Brodbeck, 2001; Hendrick & Kleiner, 2001), obstructing project performance (Brodbeck, 2001) or experiencing user reluctance or impossibility to participate (Hendrick & Kleiner, 2001). Tait and Vessey (1988) advised that user involvement does not necessarily lead to a successful introduction of a computer system into an organization; that a contingency model to account for environmental factors in the development process (e.g., resource constraints), the technical subsystem (e.g., system complexity) as well as the user subsystem (e.g., system impact and user attitudes) is important to predict the impact of the user involvement.

When direct user involvement is not justified or cost-effective at every stage of the design process, usability inspection evaluations that do not require direct user participation can be used. These are relevant to identify major issues before direct user involvement. However, they are still recommended to occur as a complement to user evaluations (ISO, 2010; Kujala et al., 2001), as the different approaches can help diagnose different usability problems (Nielsen & Mack, 1994). User participation should optimize performance and productivity (Glina et al., 2011; Vink et al., 2006) by making the product easier to understand and use, hence reducing training and support needs and costs (ISO, 2010; Maguire, 2001). It should mitigate occupational health risks and enhance well-being and safety (Glina et al., 2011; Österman, 2012; Österman et al., 2011). It should reduce the risk of mispending resources on the progress of a product that is based on incomplete or misunderstood requirements, increase user acceptance to the new design (ISO, 2010; Maguire, 2001), and facilitate more rapid technological and organizational changes (Österman et al., 2011). It should also help to elevate the reputation and competitive advantage of the organization (ISO, 2010; Maguire, 2001), increase sales for the manufacturer, improve quality and reduce production time and costs (Norman, 2013; Vink et al., 2006). User participation, promoted at the early stages of the process, has also been found to help reduce uncertainty by filling in information gaps in collaborative projects (Sjödén et al., 2016), as well as determine the usefulness of the project outcomes (Karlsen, 2002), since the end-users possess expert knowledge of the operations.

3.4 Human-Centred Design

Of the user-oriented approaches, human-centred design (HCD) is participatory and systemic, and promoted by the IEA (2018) as the approach for E/HF integration in design. It has been considered an overarching approach and one of the main design movements (Giacomin, 2014).

With the societal changes that took place post-World War II, ethnography, behavioural and social psychology began to play an increasingly important role in design, countering the traditional reductionistic methods of solving problems (Koskinen et al., 2011). The proliferation of E/HF, systems theories, participatory approaches, usability engineering and human-computer interaction (Williams, 2009) triggered the user-centred design (UCD) movement. UCD was first widespread in computer science and artificial intelligence (Giacomin, 2014; Koskinen et al., 2011), and in industrial and interaction design in the 1990s, made popular by the Silicon Valley design company IDEO (Koskinen et al., 2011). More recently, the nomenclature HCD rather than UCD was adopted by the ISO to support the involvement of all stakeholder groups that can affect and be affected by design.

The ISO offers a definition and guidelines for HCD application (ISO, 2010). It defines HCD as an “approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques”. This approach is based on four main design activities once the design and HCD project plan has been established, which are to be iterated until the project objectives are met and a suitable design solution is found: (a) understanding and specifying the context of use and environments for all relevant user and other stakeholder groups, and for their tasks and goals; (b) identifying the user needs and requirements, existing standards and devising measurable usability objectives, as well as resolving potential requirement conflicts among user or other stakeholder groups; (c) producing design solutions in the shape of simulations, prototypes or mock-ups, along with the (re)design of user tasks and user-system interactions, to meet the context of use and user requirements and account for the whole user experience (UX) (people’s satisfaction, perceptions and responses to anticipated or actual engagement with the new design); and (d) evaluating the design concepts and solutions against the requirements (with user participation and usability inspection methods). Throughout these activities, there must be multidisciplinary skills on the team, including E/HF specialists and the involvement of users (or representatives) through design and development, providing data and/or evaluating the designs. The HCD mindset is to be adopted all through the product’s lifecycle (ISO, 2010). Defining the design problem should inquire the users and contexts of use, and even understand why certain errors occur, how experienced users learn and maintain skills (Woods, Patterson, Corban, & Watts, 1996), and identify and mitigate potential operational risks (Grech & Lützhöft, 2016).

The e-Navigation programme promotes a human-centred approach (IMO, 2014a) and one of its ultimate goals is to make “maritime navigation and communications more reliable and user friendly” (IMO, 2014b, p.1). Patraiko et al. (2010) emphasized the importance of making e-Navigation ‘user needs led’ rather than led by technology or regulation. The integration of HCD principles should help to safeguard that the end-product is usable and safe (Costa, 2016; Grech et al., 2008; ISO, 2002, 2010; Maguire, 2001).

3.4.1 Usability Testing

Usability evaluations are a fundamental activity in the HCD process to diagnose problems and guide redesign (Holden, Boyer, Ezer, Holubec, Sándor, & Stephens, 2013; ISO, 2002, 2010; Jordan, 1998; Maguire, 2001). Usability is defined as the extent to which a product or service can be used by a targeted user group in their use context and environment to achieve its desired goals with effectiveness, efficiency and satisfaction (ISO, 2002, 2010). Making a product or service usable helps

to remove the ambiguity and manage the complexity of the technology, to increase learnability (ISO, 2002; Maguire, 2001; Norman, 2013), and to avoid use errors and safety risks (Jordan, 1998). The employment of usability evaluation methods refers to having subject-matter experts (E/HF specialists, users, or other professionals) scrutinize the usability of a design/user interface (Hornbæk, 2006; Jordan, 1998; Lewis, 2014; Nielsen & Mack, 1994). Usability methods can be analytical/inspection-based – based on the evaluators' judgement, general models and rules of thumb – or they can be empirical with users. These approaches complement each other as inspection methods can help to diagnose the first major issues, and user evaluations help to identify the larger percentage of problems not evident to the design team (Nielsen & Mack, 1994).

Empirical usability evaluations with users are fundamental in the HCD process (ISO, 2002). A lack of user participation might result in the new technology not fitting the user, the tasks or the environment in question, forcing the operator to look for coping mechanisms and alternate solutions (Grech et al., 2008) and diminishing user acceptance (Norman, 2013). Empirical usability methods can involve quantitative and/or qualitative data collections, such as performance-related measurements, critical-incident analyses, questionnaires, observations, interviews, the thinking-aloud technique, model-based approaches to expert evaluations (ISO, 2002; Jordan, 1998; Nielsen, 1993), eye tracking (Nielsen, 1993; Poole & Ball, 2006; Schiessl, Duda, Thölke, & Fischer, 2003). There is no one optimal participant sample size that fits all usability tests, but in most cases the first five participants will already identify 80-85% of the usability issues (Lewis, 2014; Turner, Lewis, & Nielsen, 2006). In the performance of usability tests and E/HF methods, a better understanding of the practice of HCD and the maritime context and its complexity is important for improved future designs at a systems level.

4 Methodological Framework

4.1 Methodological Overview

To address the research questions within this thesis, the bulk of work relied on qualitative research approaches and methods for data collection and analysis (Articles I-VI). Article VI, however, also involved a quantitative element in its quasi-experimental design with a mixed-methods approach through the use of eye tracking (see Figure 1).

Article I	Article II	Article III	Article IV	Article V	Article VI
• Focus Group	• Interviews • Direct Observations • Documentation	• Focus Groups • Direct Observations • Collective Interviews • Questionnaire • Documentation	• Naturalistic Direct Observations • Think-Aloud Technique • Individual and Collective Interviews	• Naturalistic Direct Observations • Think-Aloud Technique	• Direct Observations • Think-Aloud Technique • Collective Interviews • Audiovisual Material • Eye Tracking

Figure 1. Overview of the methods utilized in each of the six appended articles.

Article I utilized a focus group interview for data collection to uncover end-user perceptions of participatory and human-centred approaches applied to a marine design context. Article II describes a case study that was largely based on interviews to follow the progression of a software optimization project over a period of time, and on literature review to analyze the results and prescribe recommendations. Article III is a case study where collective interviews, focus groups, direct observations, a questionnaire and documentation were used to follow a design team's HCD activities in the redesign of a navigation interface over time. Articles IV and V were based on field studies with direct observations of a shore-based centre for navigational assistance, its operations and the technologies used. Interviews with coastal pilots and navigation instructors were additionally held for Article IV. Article VI describes a quasi-experimental study where a mixed-methods approach was used, combining the qualitative data of observations, interviews and visual and audio data with quantitative eye-tracking data. In data analyses, the data were presented as narratives (Creswell & Poth, 2018), and/or reduced, clustered and categorized into relevant themes to organize and present the main results (Charmaz, 2014; Corbin & Strauss, 2008; Creswell & Poth, 2018).

For Articles II-V, the research relied greatly on a flexible design (Robson, 2007) where data collections could not be strictly pre-specified; they had to follow a more fluid evolution, as they were based on case studies or ethnography, and on a grounded theory approach to data collection and analysis. Research questions and literature reviews were refined over time, depending on data collections. Also, the decision of when to stop collecting data depended on the pre-defined duration of a project, resource limitations or reaching data saturation/repetition (Czarniawska, 2014).

4.1.1 Procedures in Appended Articles

The summarized procedure in each appended article is as follows:

- Article I** This study was composed of a focus group session with ten Swedish cadets on the success factors and benefits of user involvement in the design of the work environment onboard. After the data collection, the qualitative data was categorized and analysed along with a review of relevant scientific literature.
- Article II** This study was composed of fourteen meetings at university and company premises over thirteen months, particularly twelve semi-structured interviews with project stakeholders and observation of two general project review meetings, to capture the company's objectives and requirements of the project, understand propeller design procedures pre- and post-software upgrade, and explore the propeller designers' expectations of how their design practice could be affected and optimal design solutions found. The data were incrementally analysed and categorized, and the identified management and user participation barriers analysed on the basis of a relevant theoretical frame of reference to prescribe potential mitigation strategies.
- Article III** This study was composed of seven reports, thirteen direct participant observations including planning sessions and user prototype evaluations, fourteen semi-structured group interviews including debriefing, five focus groups, and one questionnaire, over the course of twenty months. The study design needed to be revised along the process to adapt to its dynamics and project requirements. The data were incrementally organized into a chronological format and iteratively analysed based on a grounded theory approach to make sense of the data and build a narrative of the HCD experiment.
- Article IV** This study was composed of four independent visits to a VTS centre administered by the Swedish Maritime Authority (SMA), which included a briefing by a VTS instructor and four separate field observations with six VTSOs on different days and schedules, and one pilot planner. Also, there was a collective interview with two coastal pilots from SMA, an interview with an SMA project partner, a telephone interview with a Malmö VTSO, and interviews with walkthroughs of voyage planning activities with three bridge instructors from Chalmers University of Technology. The data were incrementally analysed and categorized based on a grounded theory approach.
- Article V** This study was composed of four independent visits to a VTS centre administered by SMA, where the first visit began with a briefing given by a VTS instructor on the general purposes of the VTS and of the specific service offered, and on how VTSOs are trained to communicate with vessels. The briefing was followed by four separate field observations of VTS standard practices with a sample of six VTSOs on different days and schedules (as in Article IV). The data were incrementally analysed and categorized into the non-technical communication factors interpreted to influence VTS decision making and the safety of operations, and discussed on the basis of a relevant theoretical frame of reference.
- Article VI** This quasi-experimental study with a mixed-methods approach was composed of nine days of simulator trials with eighteen Swedish active or recently active bridge officers (two test participants per day working as a bridge team). The trials had a voyage planning and navigation exercise and scenario. Data collection methods included direct observations with collection of audio-visual and eye-tracking material, and semi-structured collective interviews were performed to wrap up each exercise. Field notes and detailed annotations of the audio-visual material were gathered and highlighted where relevant, and memos were written. The eye-tracking data were analysed using the appropriate software.

4.2 Research Approaches

4.2.1 Qualitative Research

Qualitative research is interpretative (Creswell & Poth, 2018) and it suits the purpose of gaining a deeper understanding of the phenomenon under study, especially those with a particular nature that cannot be directly quantified (Corbin & Strauss, 2008; Creswell & Poth, 2018; Langford & McDonagh, 2003). Qualitative research is aimed at discovering variables rather than testing them (Patton, 2002).

4.2.1.1 Case Studies

A case study is, as the name indicates, the in-depth study of a single case about an individual, group, organization, process, relationship or project in a real-life setting through a period of time (Creswell & Poth, 2018). Articles II and III are classified as case studies, as they treated single cases that served as specific illustrations to a phenomenon/problem (Creswell & Poth, 2018). The term *case study* is not so much used here as a framework to how data were collected, but more as a classification or delimitation of the boundaries of the study object. However, as per the definition of *case study*, classifying a study as a case study usually implies that it will be an in-depth study of that case and hence probably involve multiple data collection methods, such as documentation, interviews, observations, recording audio-visual material (Creswell & Poth, 2018).

The case studies in Articles II and III required following the progress of a team, an object or a quasi-object (e.g., a process) for the duration of the study. This sort of research activity is known as *shadowing*. Shadowing can be compared to ethnography although it does not necessarily observe an entire community and their cultural features; it is usually more specific to the study of a practice (Czarniawska, 2007) (see 4.2.1.2 *Shadowing and Ethnographic Studies*). These case studies involved direct observations, meaning that those being observed were aware of the researcher's presence and work, and had agreed to collaborate.

4.2.1.2 Shadowing and Ethnographic Studies

Shadowing pertains to following/observing a selected group of people over a period of time in their occupations in the field. It is seen as a technique and an attitude aimed at developing knowledge, which requires *outsidedness* of the researcher and does not include providing advice to the practitioners being observed, devising 'best practices', nor empowering groups of people (Czarniawska, 2007, 2014). Article II utilized this qualitative approach to capture the progression of a software optimization project in terms of management and user involvement. Article III also utilized this approach to capture the lessons learned by a design team as they redesigned a navigation interface using HCD. These articles provide a narrative of the activities and what they entailed. Especially in Article III, following the design team with the practice of HCD can also be seen as the shadowing of HCD as a quasi-object (Czarniawska, 2007). How the team and external HCD specialist, their relationship and events developed around HCD were aspects of importance in how HCD was learned, adopted and adapted in their context. Besides Articles II and III, Articles IV and V involved shadowing/ethnographic studies of the VTS during a number of days with different VTSOs in the field. Ethnographic studies refer to the extended field observations, interpretation and description of the shared culture and behaviours of a group of people and how it works, such as those of a tribe (Creswell & Poth, 2018).

In Articles II-V, the study of a practice was performed. Be it the management and user involvement in a software optimization project (Article II), an HCD application (Article III), or the typical operations of

VTSOs (Articles IV and V), this work required in some way or another shadowing/observing these practices in the field where they occurred. In all of these contexts, there were activities being performed by or via *actants* (human and non-human, which could include technologies, objects, policies, etc.), and these activities and actants were being studied by an external person (Czarniawska, 2007).

4.2.2 Mixed-Methods Approach Embedded in a Quasi-Experimental Design

A mixed-methods approach to data collection and analysis combines the collection of qualitative and quantitative data to answer the research questions (Creswell, 2014; Creswell & Clark, 2011). This was used in Article VI where a quasi-experimental design was chosen, which defines the mixed-methods approach as an *embedded mixed-methods approach* (Creswell, 2014; Creswell & Clark, 2011). The qualitative and quantitative research methods were performed during a control/baseline condition and an experimental/intervention condition in a laboratory/simulated study (Shaughnessy & Zechmeister, 1994). *Quasi-experimental* refers to the fact that the participant sample was not selected nor assigned randomly (Creswell, 2014; Fife-Schaw, 1998; Shaughnessy & Zechmeister, 1994).

4.3 Data Collection Methods

4.3.1 Focus Groups

Focus groups were used in Articles I and III. A focus group is a type of collective interview where a selected group of members of the public (typically between five and twelve) are invited to share and discuss their perceptions on a particular topic for a couple of hours (Patton, 2002), and can be useful to collect user needs or impressions on a new concept (Jordan, 1998; Nielsen, 1993). Focus groups are steered and encouraged by one moderator and often aided by an assistant moderator (Langford & McDonagh, 2003; Maguire, 2003; Patton, 2002). This is a carefully planned occasion for which the selection of members occurs on the basis of their connections to the topic under debate. This was the case for Article I, whereas Article III did not undergo a similar selection process; the group in Article III was a design team, partner in the project. The nature of focus groups is participatory, enabling the participants to engage in the discussion (Langford et al., 2003) and to build on each other's views, enriching the discussion and the data (Patton, 2002).

4.3.2 Individual and Collective Interviews

Interviews are conversations between a researcher and one or several interviewees (Patton, 2002). This conversation is led by the researcher in a structured, semi-structured or a more flexible way, usually consisting of open questions that can incentivize the interviewee(s) to talk. Interviews were performed in Articles II-VI.

4.3.3 Direct Observations and Think-Aloud Technique

Observations entail following an individual or a group of people, a scene or an object and looking at the events related to it that are relevant to answer the researcher's research questions. Direct observations are one way to do this, where those being observed are aware of it (Patton, 2002). The researcher will in many cases have some form of interaction with the participant(s), to ask questions to clarify certain actions. Direct observations were performed in Articles II-VI.

The think-aloud technique was used mainly in Articles IV-VI. It encourages the participants being observed to speak their thoughts out loud, in order for the researcher to get their verbal descriptions of tasks and decisions but without impacting their operations (Jordan, 1998; Lewis, 2014; Nielsen, 1993; Patton, 2002; Stanton, M. Salmon, Raffery, Walker, Baber, & Jenkins, 2013). The researchers may

once again intervene when appropriate to ask clarification questions, avoiding impact to the exercise (Patton, 2002).

4.3.4 Audio- and Video-Recording

Audio-visual material captured through cameras and audio-recorders is useful to study quotes and details of the participants' experiences, tasks and perceptions that the researcher alone cannot manage to note down or analyse while running the data collection event (Nielsen, 1993; Patton, 2002; Silverman, 2014). Audio material was collected through Articles I-VI, and video capturing was used in Articles III and VI.

4.3.5 Eye Tracking

Eye tracking is a technique performed with a pair of individual glasses that contain sensors that monitor and record both the participant's eye movements in relation to his/her surroundings (as in first-person gaming), as well as audio. The data can later be analyzed in appropriate eye-tracking software. This measure was used in Article VI in a simulated experiment to test a web platform for proof of concept and usability to (a) comparatively capture how the systems were utilized and time was divided among them, and how quickly certain services and functions could be found and used, (b) provide information on perceptual challenges and action barriers, and (c) record the participants' comments when interacting with the different systems and services. Eye tracking has been considered a value added in the context of usability testing, including in simulated environments, to complement traditional usability methods with objective data on visual attention, and to inform the design of improved interfaces (Nielsen, 1993; Poole & Ball, 2006; Schiessl et al., 2003).

4.4 Data Analysis Methods

4.4.1 Narratives

Narratives are accounts that report and describe experiences, as in storytelling, of how people work and live, usually containing direct quotes from the participants and interpretation of the researcher. These accounts will normally follow the chronological order of events depending on the study (Creswell & Poth, 2018). This approach was useful in Articles II and III as they describe case studies, as well as in Articles IV-VI which describe how people traditionally operate in the workplace or how they experience standard or novel technologies in relation to the operations.

4.4.2 Grounded Theory

Grounded theory goes beyond description to generate theory and hypotheses that can be tested at a posterior stage (Corbin & Strauss, 2008; Creswell & Poth, 2018). Grounded theory is thus an abductive approach to qualitative analysis (Czarniawska, 2014) that produces new theoretical constructs and concepts from qualitative data about the social reality rather than testing existing constructs (Corbin & Strauss, 2008; Patton, 2002; Taylor & Bogdan, 1998). Data collection does not begin with established concepts – instead, the first data helps to define what to collect next and what direction to take (*theoretical sampling*), being that data collection and analysis occur simultaneously and iteratively (Corbin & Strauss, 2008; Orr, 1990). The analytical process is based on writing memos from the researcher's interpretations and ideas, on inspecting the data for symmetries of phenomena and on coding procedures to reduce, organize and interpret the data, to increase the rigor and objectivity of qualitative data (Corbin & Strauss, 2008; Orr, 1990). Data may be collected from observations, individual interviews, focus groups, documentation, audio-visual material, etc., which may be combined to explore a topic further. Articles I-V were analysed using a grounded-theory approach.

5 Results

5.1 Article I – *Perceived success factors of participatory ergonomics in ship design*

The aim of this focus group study was to investigate the perceptions of novice seafarers about the success factors for (input) and benefits of (output) end-user participation in the design of ships and ship systems. This study answers this thesis' research question 1. The results yielded a conditional/consequential matrix of perceived prerequisites and subsequent benefits at a micro and macro levels of being involved in design as end-users, ultimately expected to help promote the efficiency and principally safety of work at sea. Prerequisites included establishing contact between designers and the "right users", eliciting input from the operators of specific ship types for whom the design is directed, not forgetting to capture a 'crew perspective' as different operators may need to work together and have an impact on each other's work. The education and level of experience of the maritime operators participating in design processes was also perceived to influence their perspective on technology, hence age was suggested to be an important user characteristic to consider. Another prerequisite was to seek balance between the users' requirements and the ship owners' requirements during design decision-making, as they may not be the same. It was also suggested that users should be involved beyond the design of systems and workspaces – in rule making and purchasing of new systems and equipment to further opine on what should be more suitable for the actual work onboard. The implementation of such prerequisites would empower the users and serve as a steppingstone/platform to improving workplace ergonomics such as better interface designs, the elimination of physical hazards, controlling for system complexity, and increasing efficiency in the use of systems. Standardization across the industry (e.g., of bridge systems to make possible operator customization; of lifeboat equipment and routines across ships) was emphasized as a basic path to generally facilitating the work onboard. The ergonomic improvements and increased efficiency and safety should subsequently help the company to avoid unnecessary costs. Overall, this study draws attention to the adequate practice of participatory ergonomics in the maritime domain, the support that users may provide in defining what adequate participation is, considering their expertise, and the benefits that this may imply for improved designs onboard ships.

5.2 Article II – *A case study of user adherence and software project performance barriers from a sociotechnical viewpoint*

The aim of this case study was to document a university-company project optimizing an existing marine propeller design software in terms of management and end-user involvement. This study answers this thesis' research question 2. The project involved a university researcher developing and deploying the optimization algorithms for a marine propeller company's software. Members from the company were assigned to collaborate with the developer, including an end-user of the software (propeller designer) assigned to be a contact person to the developer and help him understand the existing version and identify problems in the optimized version(s) during development, as well as the remaining propeller designers at the company to help test the optimized software in real-life propeller design cases and report bugs during development. The will of the company management and of the developer to directly include all of the company's propeller designers and both gather their technical expertise and get them to functionally test the upgrade versions for improvement was evident. Yet, the involvement of the end-users was met with some barriers which hurt the activities and momentum of the project to some extent. An important barrier was that the opportunity, decision and conceptualization of this optimization project were negotiated between the company and university, and only posteriorly

during development and deployment were the users requested to participate. This meant the users were involved solely in a software testing capacity where the relevance or impact of the algorithms could no longer be questioned or halted in the same way. Another barrier was of stakeholder roles and task centralization. Although this project was collaborative, the principal tasks converged to the developer who was not co-located with the users and the management team, hence making it difficult to maintain continuous direct communication with the users whilst working on the algorithms from the university. User attitudes and expectations towards the optimization, such as perceived relevance and trust in automation, could not be fully represented or transmitted by the assigned contact person nor fully captured or considered in the process. Applying the software upgrade, especially an unfinished version, to real-life propeller projects in progress was perceived by the users as a high-risk activity if the output was not reliable and could cause a negative effect on work effectiveness, which would implicate more time and resources for double-checking until the software upgrade could be trusted. Although the users recognized increased efficiency and company productivity as potential benefits of the upgrade, they expressed reservations towards the automation of a set of decisions that were originally made by them based on their experience and knowledge, being this perceived as a risk for skill development. Another barrier regarded project management strategy and deadlines for delivery or lack thereof. There was no clear separation of the design stages or a clarification of when the users were expected to intervene, and only late in the project did the management team begin to implement milestones and deliverables, and to document the process. Another barrier was that the users repeatedly emphasized the high workload with propeller orders and lack of time for trying out the new software upgrade, including for attending meetings booked by the developer to provide software information and training, testing and troubleshooting. The integration into daily work relied on the users' own initiative, as it was not made mandatory nor was a deadline established by the management team or the developer. The motivation to do so also seemed negatively affected by the fact that the software was not finalized, so learning an alpha or beta version that was likely to suffer alterations and have to be relearned was not prioritized among dominating tasks. The users also expressed an increased wish for training with higher levels of automation to grasp system's operations and decision-making, which connects to the next barrier: although contradictory to the users' tight schedules and high workload, the users expected more meetings with the developer for instructing them on how the software was intended to be used in order not to have to dedicate time to learning it by themselves. Based on a review of literature, it was suggested that a management strategy that can take account of the sociotechnical nature of the project, help guide user involvement from an earlier stage and capture user requirements and social aspects should stimulate user adherence to testing the new software, subsequently maximize knowledge transfer capabilities and help to avoid related project delays.

5.3 Article III – *Implementing human-centred design in the context of a graphical user interface redesign for ship manoeuvring*

The aim of this case study was to investigate a case of human-centred redesign of a bridge wing interface for ship manoeuvring by a team of engineers from a maritime consultancy firm that did not have HCD as regular or standardized practice. This study answers this thesis' research question 3. It explored how HCD was interpreted and utilized and how HCD benefits could be achieved. The support and strategies to practice HCD came from the external EU project which this company was part of, and its partners. The HCD process became organically structured into three principal stages that can be titled Pre-design, Design, and Final Evaluation. The Pre-design stage consisted of going backwards and forwards between learning about HCD, planning the process, and understanding simultaneously user requirements and context of use for the bridge conning display. These activities fed into one another

and kept progressing as the first design sketches were produced and evaluated with users during the Design phase. The Design phase involved four iterations of paper-based design sketches and prototypes. The Final Evaluation consisted of a scenario-based trial in a simulator. During the whole process, there were literature references and E/HF methods – especially those recommended by the E/HF specialists in the project – that had an impact on the team’s design decisions. Yet, the team generally needed expert advice and hands-on support collecting the references and methods (as there were various and extended sources of E/HF information), interpreting, adapting and applying them, and feedback indicating whether they were on the right track. Communication and knowledge transfers within the team and between the team and the appointed HCD specialist (not co-located liaison) implicated defining individual roles and powers, and establishing a mutual HCD language and understanding. The choice/uptake of methods and steps to follow next usually underwent negotiations between the team and the HCD specialist or literature advice. This project was always competing with other parallel work the team members had within their company. Of the activities performed, having users do a walkthrough of their tasks and equipment used onboard was perceived as especially useful, as well as benchmarking existing designs and making a feature list to review and prioritize with users, and discussing the design sketches and prototypes with users. The team highlighted involving the users early in the process, understanding the context of use, testing with users and iterating as the main takeaways and values added of HCD.

This narrative emphasized HCD practice and knowledge production as a situated experience. The roles and relationships of the actors involved, their expertise and maturity with E/HF methods, the organizational practices and support, the interpretation of E/HF literature and their shared mental models of it, and the competing projects and workload determined the uptake of HCD. Hence, appropriate communication and knowledge transfers are needed, where E/HF specialists can help create a shared language and provide hands-on support to guide the process and the interpretation and application of E/HF literature and methods. These findings contribute to further depiction and adoption of E/HF methods and design approaches for engineering projects.

5.4 Article IV – *Identifying gaps, opportunities and user needs for future e-Navigation technology and information exchange*

The aim of this study was to investigate the current maritime network, typical work practices and technologies to identify current e-Navigation technology gaps and potential development opportunities. This study answers this thesis’ research question 4, along with Articles V and VI. The results from the observations at a VTS centre and the interviews with pilots and bridge instructors suggested that anti-collision and anti-grounding strategies were central for the participants both in voyage planning and execution for the maintenance of maritime safety. Achieving this common goal in local waters requires a complex network of maritime stakeholders and information systems to share data, coordinate decisions, and monitor/control operations. Among the identified gaps was the compartmentalization of relevant navigational information and limited access to local information such as detailed local weather and bathymetric information, navigation and traffic patterns, and closest points of approach (CPAs), requiring multiple sources and communication channels to gather round all relevant parameters/details for each voyage. Another important gap was even the discrepancy of commonly used tools and accessibility of local information among shore-based operators (e.g., among pilots and VTSOs), and that basic information such as a vessel’s draught found on the Automatic Identification System (AIS) information was not usually updated or trusted and was hence requested from vessels repeatedly by different operators – even those who were collocated (e.g., VTSO and pilot planner). Potential was thus demonstrated to link frequent and automated draught measurements with AIS information (and potentially with shallow water contours on the

charts) and make sources more reliable and information more integrated and synchronized, to improve efficiency, reduce uncertainty and repetitions via the VHF radio, and support communication and cooperation among the operator network in voyage planning and execution despite the geographical distribution. Other parameters such as water levels and currents were reported relevant for the vessel's draught, and this information could potentially, in the future, be received as an incorporated part of the ECDIS for quicker integration and adaptation of the voyage. Also, an opportunity was identified – considering the lack of a full common picture among stakeholders – for route sharing to help operators predict the movements of others and plan their own. There is also an opportunity for storing, analysing and transforming historical local data (e.g., traffic patterns, typical voyage plans, water currents, winds, CPAs, and incidents) for better information integration. Other opportunities point at revisiting certain regulations/recommendations or lack thereof together with the development of new technological capability (e.g., (a) hiring a pilot had a key impact on the access to local information, but this was not mandatory in all ports; (b) it was not mandatory to take regular measurements of the draught connected to AIS for increased accuracy; (c) there was no capability to identify and contact smaller vessels), and at reinforcing training of ECDIS systems.

This study demonstrates technological gaps and opportunities, but it also draws attention to future research and development to consider issues of introducing new automated technologies and of transforming the structures of the maritime industry, and of how the operators will be educated and their skills maximized. Moreover, if the maritime domain is to adopt a new global technological infrastructure, then training, standards and regulations must be put in place alongside, and the transition must be managed to incite global adoption and increased standardization.

5.5 Article V – *Non-technical communication factors at the Vessel Traffic Services*

The aim of this study was to describe the non-technological aspects of everyday communications and operations in receiving and transmitting local information at the VTS to assist passing vessels in maintaining efficiency and safety. This study answers this thesis' research question 4, along with Articles IV and VI. It was observed that an individual VTS workstation is mainly characterized by the VHF radio communications and the computer screens with the electronic charts with integrated radar and AIS information, along with the use of other information systems or services (e.g., email, pilot schedule, weather forecast), through which the VTSO monitors the traffic situation in their respective VTS geographical area, requests ship details, and provides remote assistance. It was observed that the VTSOs needed to cope with the limitation and uncertainty of being geographically separated from the vessels by utilizing the radar, AIS information and VHF radio communications to make judgements and safety decisions on which of the vessels to prioritize in terms of how much assistance to provide or how much trust to bestow upon them. The VTSOs perceived that ship and shore operators have different perceptions of reality in the sense that, for example, bridge officers and pilots onboard have a possibility to see ahead and predict certain movements and events in the fairway that the VTSOs cannot. The VTSOs also felt limited as to the assistance that could be provided, related to how much or how little power the VTSOs felt they could exercise over the vessels stemming from the ambiguity of the separating line between the different roles of VTS centres (Information Service (INS), Traffic Organization Service (TOS), Navigational Advice and Assistance Service (NAS)), as well as related to the perceived receptiveness of ship bridge officers.

The VTSOs normally expressed higher trust in the frequently passing vessels such as the local ferries (with pilot exemption) and the skills and local knowledge of their crews, or in bridge officers or pilots that they personally knew. They even accepted certain ship manoeuvres from these vessels that would

not otherwise be accepted from other vessels, as they were expected to have a good grasp of the risks and have enough local bathymetric knowledge to make those decisions. From less frequent vessels, language proficiency was an aspect that influenced how much trust was bestowed. If the nationality of the officers was perceived to commonly be proficient at the English language, the VTSOs would show less concern for the possibility of miscommunication. The VTSOs' experiences with cultural differences of how crews operate onboard was also an aspect that influenced how much attention was paid to the vessel. Vessels deviating from what the VTSOs considered normal navigation would be given more attention, even though these 'norms' were often not only based on formal directives but also on local and informal customs. When the VTSOs deemed vessel-to-vessel or vessel-to-VTS communications clear enough and intentions seemed understood, vessels would be given space to act on what had been agreed upon, and a closed-loop communication model would not be prioritized or deemed necessary in such circumstances.

This knowledge represents an opportunity for future shore-based assistance organizations, regulations, training programmes and technical solutions to further support operator needs. Specifically, it may contribute to authorities such as the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) in their considerations towards the homogenization of the delivery of VTS, and to manufacturers, policy makers, educators and trainers on considering the hard and soft aspects of communication in the design of ongoing and future e-Navigation support systems, policy developments, VTS education and training programmes for the augmentation of safe and efficient passage in dense and confined waterways.

5.6 Article VI – *Assessing a maritime service website prototype in a ship bridge simulator: Navigators' experiences and perceptions of novel e-Navigation solutions*

The aim of this quasi-experimental study was to evaluate with mariners a novel maritime service website prototype (BalticWeb) for proof of concept and usability in a ship bridge simulator. This study answers this thesis' research question 4, along with Articles IV and V. The prototype was meant as an aid to existing systems and methodologies for voyage planning and navigation and included four services: standardized VTS reporting, real-time MSI promulgation directly on the charts, fuel-saving-based route optimization, and no-go area contours based on vessel draught and hydrographical weather data. The results showed that gaps in the current technologies and methodologies could benefit from the tested services, especially during voyage planning compared to navigation, and if integrated and IMO-approved as an integrated part of the existing systems rather than as an extra tool to an already complex environment. The eye-tracking data showed that the standardized VTS reporting format helped to reduce VTS reporting activities and VHF communications by half, but that the real-time MSI promulgation directly on the BalticWeb charts did not necessarily help with identification or to reduce the workload of the mariners, being that this was not an approved tool and hence the same information was still required from the standard navigational telex (Navtex) and on the standard ECDIS. Yet, the possibility of receiving MSIs in real-time and directly on the charts and along the voyage was perceived very positively. The route optimization service was criticized for not accounting for COLREGs and for requiring a pre-route rather than simply the voyage and ship details in order to run its algorithms. With regards to having to share a pre-route with a service provider for optimization, and with regards to having to send out various types of reports beyond the VTS, there were suggestions by the participants and have been technical developments (e.g., Danish Maritime Authority, 2018) of route sharing between vessels and shore-based authorities for easier exchange of information. One of the participant groups considered the no-go area service unreliable for a route planning purpose, as

planning a route based on hydrographical weather data would signify basing it on dynamic data that can change between the time of the planning and the time of the execution. Yet, it was considered pertinent for navigating areas with tides, currents, winds or bad visibility. Tools onboard must not be limited by internet connectivity issues, and tools that assist decision making must be IMO-approved.

Information, especially in route planning activities, proved once again to be compartmentalized, repeated in different sources, not always consistent, and cumbersome to access as it is, hence indicating that an added tool would instead be more useful as integrated and cohesive functions of the existing systems to facilitate the collection of all relevant information through one single platform without unnecessary nor inconsistent information repetitions from various sources. Although there may be challenges to integrating even more information and functionality to the existing ECDIS, this was preferred by the participants so long as overlays and functions can be turned on and off to simplify the ECDIS screen to a more basic level when needed.

6 Discussion

6.1 The Practice of E/HF Methods and User Participation

Article I draws attention to fostering contact and communication between the relevant maritime operators (considering their expertise and experience levels, and taking a crew perspective) (see also Grech and Lützhöft, 2016) and decision makers in design processes to benefit the onboard work conditions as well as the company business. Articles II and III present two case studies of internal exploitation and redesign of an existing company software and graphical user interface redesign, and of development practice where users were involved as part of the process. Whereas Article II describes a case where no particular design or project management style/strategy was officially defined, Article III describes a specific project with HCD implementation. The first focuses on the user involvement and the organizational barriers encountered through the project, and the latter focuses on the challenges of an HCD approach by HCD novices. In Article II, the intention and will of the company and developer to involve the users continuously through development and deployment of the optimized software version was evident. Yet, the important step of early user involvement during conceptualization and planning was not recognized or realized. During development and deployment, the management strategy was *ad hoc*, and there was a limited platform for continuous communication of intentions and knowledge exchange between the developer and the users. The human element/actor variable (Leavitt, 1965; Lyytinen et al., 1996) such as the user attitudes towards the technology (e.g., lowered perceived system usefulness (Venkatesh & Bala, 2008)) and the potential negative effects of the optimized software on the users' work tasks (e.g., being left with the residual functions of the technological automations (Hendrick & Kleiner, 2001)) and skill development were then missed, which led to a misalignment between the objectives of the project and the expectations of the users when trying to engage them. An alignment requires maintaining strong ties through the process (Arroyabe et al., 2015; Lee, 2000), having continuous communication and collaboration (Sjödin et al., 2016), and information sharing across environments (Lyytinen et al., 1996). To capture the aspects at the human element/actor level and increase acceptance and adoption (Maguire, 2001; Norman, 2013; Venkatesh & Bala, 2008), early user involvement and analysis of the impact of the technology is recommended to help establish design alternatives (Bligård et al., 2014; Hendrick & Kleiner, 2001; Lyytinen et al., 1996), amplify the capabilities necessary for appropriate and effective knowledge exchange in the project (Parent et al., 2007), and better prepare the users for the change (Schein, 2010; Tait & Vessey, 1988). A participatory and holistic approach can not only be used to improve upon the usability of the end-product, but also as a way to support the management strategy of the project (Giacomin, 2014; ISO, 2010), the achievement of the business goals and competitive advantage, and increase quality (Dul & Neumann, 2009).

The narrative in Article III emphasized HCD practice and knowledge production as a situated experience. The roles and relationships of the actors involved, their expertise and maturity with E/HF methods, the organizational practices and support, the interpretation of E/HF literature and their shared mental models of it, the competing projects and workload, determined the uptake of HCD and E/HF methods. Attaining a shared and concrete E/HF language within the team and with the appointed HCD specialist in the project was a process (see also Grech and Lützhöft, 2016), and the non-collocation of the HCD specialist and sporadic meetings prolonged this process. The translation of interests (leveraging of different views) and establishment of common ground among the members became then a series of negotiations to establish and achieve their goals (Latour, 1987) about which problems to address, how to address them, what solutions to develop, and revisiting topics (Steen, 2008). Hence, appropriate and continuous communication and teamwork among the involved parties are needed as

they have an impact on the generation and flow of knowledge (Parent et al., 2007), and adaptation of the project, as well as on building trust and on the creation of a common understanding of the goals and steps in the project. This need for continuous communication to keep adapting the project together was a common trait of Articles III and II. It was still noted that the E/HF specialist was essential in providing guidance through the HCD process and the interpretation and application of E/HF literature and methods that were otherwise not always straightforward to transform into concrete application. Also, besides the specificities and dynamics of every situated human activity and practice (Nardi, 1995), the adaptation of generic HCD guidelines from the literature and selection of methods to the specific industrial context and project at hand, as well as their appropriate integration within the organizational structure, are vital to the success of the application (Andersson et al., 2011). The way for HCD-novice firms to view HCD is that it is less of a set rigid plan than a mindset and an adaptable collection of tools to get the information required to support design with input from the users and their context of use. These findings contribute to further depiction and adoption of E/HF methods and design approaches for engineering projects.

Design and engineering are demanding and complex activities with organizational and technical constraints (Broberg, 2007). Moreover, the variety of requirements coming from all potential users and the need to coordinate them in design may reflect a wicked problem (Buchanan, 1992; Lurås, 2016). Hence, E/HF techniques and user involvement activities should be guided by E/HF specialists as part of the design team (Andersson et al., 2011), who have specific training to gather user needs (Kujala et al., 2001) and who can also convey the value of E/HF across the functions of the organization where it is to be implemented and even in terms of shareholders and how ergonomics can support the organization with creating competitive advantage (Broberg, 2007; Dul & Neumann, 2009). This is especially important now that the maritime industry is suffering the demand for increased efficiency and being pushed by the e-Navigation initiative to implement a human-centred approach for further digitalization and information flow across ships and shore.

The lessons learned from the experiences observed in Articles II and III add to Article I in terms of success factors for HCD and user participation. The knowledge gained from Articles II and III also complement the holistic model for maritime HCD in general design of ships and ship systems presented in the author's Licentiate thesis, Costa (2016), of which Article I was also part.

6.2 Preparation for Technology Change: A Systems View

Also present in the author's prior work, Costa (2016) (see *1.1 Research Background*), is the systems view, intrinsic to the HCD approach. The research in Articles IV-VI provided groundwork – as per one of the first activities in an HCD process – and knowledge about current maritime operations to be taken into consideration in ongoing and future developments in the domain. The work described the current ways of working for maritime operators onboard and ashore, and made evident that certain gaps exist and have the potential to be aided and streamlined by today's technological capability. Although Article VI was specifically about the testing of a novel e-Navigation tool to collect user feedback for design refinements, it also offered comprehensive insights into generic bridge operations that can be useful in the design of other tools, training and education programmes, and the adjustment of certain processes and regulations. Article V describes a facet of the VTS that not only provides knowledge relevant for the further development of regulations and training programmes, but also for future technical solutions to further integrate them, support shore-based assistance operator needs and situational awareness. Specifically, it may contribute to authorities such as IALA in their considerations towards the homogenization of the delivery of VTS, and to policy makers, educators and trainers, and manufacturers on considering the hard and soft aspects of communication in the design of ongoing

and future e-Navigation support systems (see also Bruno and Lützhöft, 2010; Praetorius and Lützhöft, 2012), policy developments, VTS education and training programmes for the augmentation of safe and efficient passage in dense and confined waterways.

The creation of the open-source BalticWeb platform for web-based services (Article VI) may be an idea for filling some of the existing gaps such as information compartmentalization (see also Grech and Lützhöft, 2016), for a ‘paradigm shift’ (Grech & Lützhöft, 2016) in bridge and information exchange technology in the domain, and an important push for manufacturers towards more digitalization and modern information sharing, standardization and customization. This does not, however, guarantee usability nor adoption by the industry. It was identified in Article VI, for instance, that current bridge operators do not necessarily call for adding even more tools to today’s already complex bridge set-ups but further integrating them into the existing information sources and improving the existing approved ECDIS, as was proposed by Porathe, de Vries, and Prison (2014) (see also Conceição et al., 2017). Another reason to question the trustworthiness and dependability of the BalticWeb was the knowledge that it was not officially IMO-approved for seafarer decision making. Ma et al. (2016) identified that the operators need some form of organizational support, directive or infrastructure to increase their likelihood of accepting new tools. In the case of the BalticWeb, these results were indicative that the regulations pushing for e-Navigation and further digitalization may be the same ones stopping its progress and adoption. It was identified in Articles I, IV and VI that standardization across the industry (e.g., of bridge systems) was perceived as a basic path to generally facilitating the work onboard (see also Grech and Lützhöft, 2016).

The shipping industry is an intricate network of social and technical elements (Conceição et al., 2017; Costa, 2016; Grech et al., 2008), hence updating, adding or replacing technology on one end of the network can stretch out and affect regulations, standards and policies, job designs and processes – alter them, eliminate them or even instigate new ones. In this sense, the work in Article I demonstrated the seafarers’ perceived value-added of being involved beyond design to regulatory and purchasing processes. This is corroborated in the results by Österman, Rose, and Osvalder (2010) that showed that employee participation in organizational decisions about business operations and purchasing processes was perceived by seafarers as important. This suggests user participation at a more systemic level in the domain. This calls for the attention of all change makers and opinion leaders in the domain towards the human element, for sustainability and social responsibility. This means not only the designers and developers, but also the managers, rule-makers and educators are invited to seize the value of E/HF (Dul et al., 2012) in further developing the domain in a time where pressures exist to optimize efficiency and information integration and exchange through innovative technology, and the complexities are ever-increasing (Man et al., 2018a). Also, inciting change in large contexts requires more than technological solutions to a problem; it may require understanding the organizational, social and political forces behind it (Vicente, 2008).

Paperless, digitalized technology with the capacity to render big data may be the next step to more efficient information retrieval, sharing, communication and decision making, before the more radical transition towards the widely discussed unmanned ships. Yet, e-Navigation developments will affect the ways in which maritime actors work (Conceição et al., 2017; de Vries, 2017), how they obtain and process information and knowledge is created and mobilized (Man et al., 2018a), as well as the arrangement of maritime communications, and ship and shore stakeholder roles (Bhardwaj, 2013) if more decision-making power is shifted to technology. It is crucial to consider social sustainability and how maritime stakeholders will be trained and their skills maximised. Another consideration is whether more access to readily usable local information and integration in voyage planning and execution would expand the potential for a centralized capacity of traffic monitoring and assistance

(de Vries, 2015) or instead render navigators more and more independent from shore-based assistance services, emphasizing the control-distributed nature of the domain (see also van Westrenen and Praetorius, 2012). Making current operations ‘leaner’ through new automation, and downsizing the crew can also have negative effects, such as operator overreliance or resistance, dealing with the amount of information (Grech et al., 2008) or how it is presented (Oh, Park, & Kwon, 2016), or not have the technology be adopted if not perceived usable, useful and a value added (Chen & Huang, 2016; Grech et al., 2008; Ma et al., 2016; Mallam et al., 2017; Schepers & Wetzels, 2007). Automation may increase performance and efficiency for the company but leave the operators out of the loop (Grech & Lützhöft, 2016; Lützhöft et al., 2011) with only the monitoring tasks that the machines do not do (Bainbridge, 1987; Grech et al., 2008) or lead them to automation-induced errors (Bhardwaj, 2013; Grech & Lützhöft, 2016; Lützhöft & Dekker, 2002), hence putting safety at risk. Lean production has also been reported to result in reduced operator well-being, satisfaction, control of the operations and usage of skills (Dul & Neumann, 2009), which could also potentially apply to ‘leaner’ bridge operations. Also, specifically automation for bridge systems has been reported to help enhance performance and efficiency of navigation but not necessarily reduce workload or keep the human operator in the loop and with full situational awareness if the human-system interaction is designed suboptimally (Lützhöft et al., 2011).

Working onboard is undoubtedly recognized by the operators as safety-critical, as suggested in Article I (see also Costa, 2016; Costa & Lützhöft, 2014). The propagation of technology is usually linked to the notion of societal progress and development (Bhardwaj, 2013), thus Information Technology (IT) and digitalization may be perceived as value added in the maritime domain. Be as it may, all this novelty does not necessarily guarantee the maintenance of safety, especially if it occurs as a result of *technology push* – which has been described to dominate IT applications in this domain (Man et al., 2018b) – without the fundamental consideration of the human element and operator needs (Patraiko, 2007; Patraiko et al., 2010) through design, implementation, training and operational use (Conceição et al., 2017). This can be especially risky in safety-critical work settings where the operators are not given access to alternative work systems (Jordan, 1998). Building fail-safe systems and avoiding all errors may be impossible, but in contexts like the shipping industry, errors can simply become too costly at many levels. To impede these costs, more design, testing and training may need to be put in place (Weinschenk, 2011). What is more, the more design and testing go into the process, the less complex the systems should be for the users to learn and hence training needs may also be decreased (Grech & Lützhöft, 2016; ISO, 2010; Maguire, 2001), which is something that was observed to be lacking with regards to the existing complex ECDIS systems (Articles IV and VI). Errors in a system will tend to increase as more channels are blocked from information transfers (Skyttner, 2005). Thus, the development of new e-Navigation tools or the update of the existing ones needs to have E/HF in mind in terms of if, when, where and how to enhance information exchange from “a holistic and systematic manner” (Graff 2009, p.181) that accounts for all involved ship and shore-based stakeholders, how the domain as a whole might be affected and how it might be forced to adapt in terms of work, regulations, training and even cyber-security aspects.

6.3 An Updated Holistic Model for Maritime HCD

The research and the appended articles in this thesis help to complement and further understand the holistic model for maritime HCD in general design of ships and ship systems presented in the author’s previous work, Costa (2016). Figure 2 wraps up the main message from Articles I-VI in this thesis, by illustrating through the triangular activity theory model by Andersson et al. (2011) that the teamwork of the design team with the HCD specialist(s) and the articulation and application of HCD techniques and principles will impact the design outcome, which in turn will help determine the users’ operations.

As per Figure 2, when practicing the HCD approach within a shipping context, the success factors of user involvement identified in Article I should be taken into consideration. By adopting the HCD approach, the consideration of the use environment (Lyytinen et al., 1996) must involve a systems view, as demonstrated by the 'onion' representation of the system's layers and elements based on the sociotechnical systems models by Dul et al. (2012); Grech et al. (2008); Vicente (2006). This suggests that the update and implementation of new e-Navigation technologies can have an impact on the other system elements and vice-versa. Ultimately, this perspective would contribute to achieve the benefits listed in Article I for increased overall efficiency and safety in the domain.

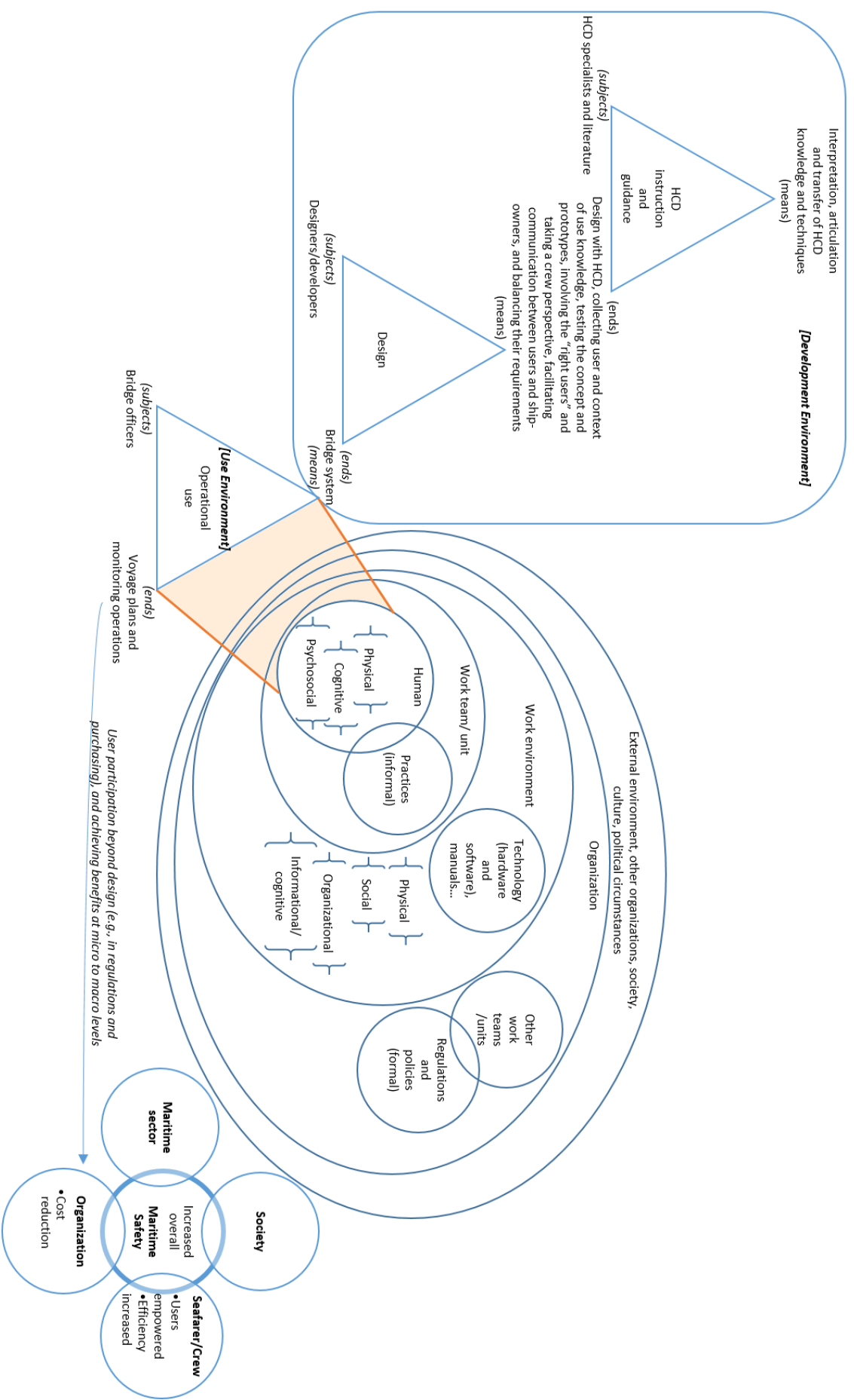


Figure 2. An updated holistic model for maritime HCD (based on the model by Costa, 2016).

6.4 Methods Discussion

The exploratory nature of the research questions in this thesis and appended articles required going into the field with “eyes and ears open” (Czarniawska, 2014, p.145) and hence that more flexible research designs (Robson, 2007) and a primarily qualitative research approach to data collection and analysis would be implemented (Creswell & Poth, 2018). The qualitative research was not necessarily intended to render statistical data and thus the generalizability of the results in articles I-VI may be limited. However, they (a) provided an interpretation and understanding, through description and themes, of the problems under investigation and their meanings in a natural situated setting (Creswell, 2014; Creswell & Poth, 2018; Patton, 2002; Silverman, 2014), (b) contributed to theory and practical knowledge for further academic and industry developments, and (c) may be transferrable or extrapolated to similar contexts (Patton, 2002), and their consolidation with the results of other comparable studies can potentially bring about ‘analytically generalizable’ findings and new theory (Creswell, 2014; Yin, 2014).

Replication of the methods utilized in this research is possible, but dependability and outcomes may vary depending on the researcher applying the methods and interpreting results, the sample, and other factors. The results told the story of the participants’ experiences and answers through the eyes of the researcher (Corbin & Strauss, 2008). In this case, Article I obtained confirmability of preliminary results during the focus group session with the participants, and the remaining articles benefited from the triangulation of several data collection methods meaning that the research relied on multiple datasets rather than a single one (Creswell & Poth, 2018; Robson, 2007). Also, qualitative research may face external validity shortcomings associated with lack of representativeness, yet the structure of the data analysis methods chosen strengthens their ecological validity. Dense naturalistic descriptions and narratives of the scenarios observed, and participant citations, can increase reliability – as in Articles II and III, to transmit the experiences and perceptions of participants, to convey to the reader the time and setting where the study took place and the richness of the data (Creswell, 2014; Patton, 2002), which ensures greater transparency in the relation between the data and the analysis (Silverman, 2014). Visualization tools such as tables, mind maps, diagrams and matrices (Creswell, 2014) were also used to help complete the picture, summarize, organize and demonstrate relationships between concepts or features identified in the raw data in Articles I-III and V.

More specific to each appended article, the methodological limitations were considered as follows:

- Article I** The participant sample was chosen for having a fresh view on onboard operations as university students and cadets at sea. Beyond their seafaring expertise, there could not be certainty about the level of knowledge and experience they possessed with regards to human factors and design, although an introduction to human factors had recently become part of their curriculum. There is a risk with focus groups that the participants do not dare to speak their mind (Krueger & Casey, 2009), or they answer in a manner that they believe they are expected to answer, or that a false consensus is created in the group (Taylor & Bogdan, 1998). With qualitative methods, as with this focus group session, external validity may be limited. However, the preliminary results were confirmed with the participants during the session, and the structured data analysis strengthens ecological validity. Focus group interviews promote reflections and reveal group norms, values and divergent opinions that otherwise may not emerge outside of a group situation (Bloor, Frankland, Thomas, & Robson, 2001; Patton, 2002; Taylor & Bogdan, 1998).
- Article II** The “outsidedness” (p.45) of the researcher has the advantage of allowing the researcher to gain an understanding of the world being observed diverse from that of the actors

themselves (Czarniawska, 2014). It was not the intent of the qualitative techniques to provoke behavioural pattern changes, hence they are considered passive or non-participatory (Czarniawska, 2014). Yet, the project stakeholders who were interviewed were aware of the researcher's research and background, which may have caused unintentional impact.

Having had the chance to follow the project only after the first negotiations and developments had already taken place, and the geographical distance from company premises, were limitations in this study. Instead, systematic meetings with the developer took place, trying to capture the object of study as well and comprehensively as possible. Although the events missed by the researcher were reported back by the developer, this cannot replace own observations. Also, due to the nature of the developer's contract at the university, the software development became temporarily interrupted until a subsequent position was defined, and this meant an end in the researcher's data collection.

- Article III** Similarly to Article II, direct influence on the design process was avoided by the researchers (i.e. *outer loop*), as they were meant to collect data on the HCD experiment as outsiders and not as team members or as human factors advisors to the design team (Czarniawska, 2014). Yet, indirect/peripheral impact was inevitable (e.g., the regular data collection meetings could have inadvertently activated the design team to focus on HCD issues) and/or due to project requirements. Nonetheless, the researchers did not change positionality with respect to the design team throughout the study, remaining as outsiders. Reliability and credibility were attained through extensive engagement and observation, and through triangulation of data collection methods (Lützhöft, Nyce, & Petersen, 2010).
- Article IV** The qualitative approach with field studies, observations and interviews suited the purpose of investigating work activity and technology within dynamic environments (Maguire, 2001; Stanton et al., 2013). The representative VTS data was used as a starting point to efficiently capture the stakeholder network and the conduct of a large number of vessels, followed by the interviews with pilots and bridge instructors. Seeing that much of what was captured is regulated and used in a standard manner, the inferences taken in this study can be indicative of the mechanisms of the larger maritime network, and offer insight into further e-Navigation developments.
- Article V** The qualitative research approach suited the purpose of providing a description of non-technical phenomena. The VTSO sample was representative of this particular centre and the number of visits resulted in data saturation (Czarniawska, 2014), thus it is argued that the inferences taken in this study can be indicative of the mechanisms of other centres with the INS role. The methods used in this study are replicable. Grounded theory analyses are not meant to be rigid, as they can be done at different levels of analysis (Corbin & Strauss, 2008; Langford & McDonagh, 2003), but the careful inspection and search of symmetries in the data ensure ecological validity and the rigour of the findings (Corbin & Strauss, 2008; Orr, 1990).
- Article VI** The conclusions taken from this quasi-experimental study resulted from empirical evidence that is indicative of the mechanisms of overall bridge procedures and information use during route planning and navigation. This study has a transformative role (Creswell, 2014), as it consists of *research about* and *for/into design* (Lurås, 2016), specifically about and for the design refinements of the tested website and services, as

well as to prescribe some directions for general further developments of e-Navigation solutions.

The trials required the participants to use the available systems which they might or might not have been familiar with and which signifies that some participants may have had an advantage over others. Be as it may, this was useful to demonstrate how the same system in a different version or manufactured by a different company is not immediately straightforward and requires time for habituation. Some procedures may have differed had the participants been more familiar with the available systems, such as making checklists on the route planning software, using the MSIs on the ECDIS or the replay button during navigation.

The planning exercise was arranged to take place within two and a half hours, which was calculated with the simulator managers prior to study to be able to fit in all basic tasks of planning a short voyage. Nonetheless, all participants referred to this schedule as too short to make a detailed plan from the start had it been a real-life situation. The readily available printed papers also accounted for the needs of any bridge and voyage plan, and spared time in the exercise. However, they implied a bias in the study, as the participants may have used different sources or not looked up certain information that was made available here had they searched for it themselves.

Laboratory studies have been questioned for their limited representation of the reality of complex systems, hence field studies are considered by some more valuable in covering the variance of factors in real practice in real settings (Jordan, 1998; Wilson, 2014). However, laboratory studies are common in usability tests and advantageous for comparison purposes (Jordan, 1998). It was pondered if the assessment of the new platform and its services should have been performed in an isolated manner (each service isolated from the others, and the platform isolated from the existing bridge systems) to avoid affecting construct validity. Still, it needed to be taken into consideration that the platform and services were meant as an aid to other systems, so in order to ensure ecological validity, it was only realistic to test it in a scenario where all systems were complementing each other. For this reason, the control/baseline condition was all the more important.

7 Conclusions

This thesis has investigated the benefits of an E/HF approach to design, or HCD, and discussed based on a focus group study (Article I) and two case studies (Articles II and III) barriers, challenges and success factors in its practice. It also aimed, based on a human-centred approach, fieldwork, interviews and a usability test of a novel e-Navigation tool (Articles IV-VI), at understanding maritime operations and information technology, and gather user feedback for direction and further development of the e-Navigation programme.

The main findings from this thesis are:

- The maritime domain is recognized as a safety-critical environment and hence safety is the ultimate goal of participatory design for ship systems. Benefits of participatory design can be achieved at different levels, such as user empowerment, workplace ergonomics and efficiency improvements, as well as increased safety and reduced costs for the company. Standardization across the industry (e.g., of bridge systems) was emphasized as a basic path to generally facilitating the work onboard.
- Establishing contact between designers and the “right users”, capturing a ‘crew perspective’, and balancing requirements from users and ship owners were suggested by novice seafarers as success factors for a participatory approach to the design of ship systems. It was also suggested that users should be involved beyond the design of systems and workspaces. It would be a success factor that they would become involved in rule making and purchasing of new systems and equipment that equally impact the operators and operations.
- The action of continuously involving the users in a design and development process for testing, such as what occurred in Article II, allows them to be part of the outcome, hence strong ties and continuous communication of intentions and objectives are important to maintain engagement and to capture non-technical aspects of their user experience with the tool being developed. This signified that technology testing was insufficient, as it did not inquire the users on their attitudes and expectations.
- As seen in Article III, teamwork and communication for a shared E/HF language among the design team and HCD specialists is key in interpreting, adapting and practicing the HCD approach, understanding that it is not a strict step-by-step approach but a mindset and adaptable toolbox of techniques to inquire the users’ needs and environments of use.
- IMO’s e-Navigation initiative aims to increase safety and efficiency of maritime operations by digitalizing information and facilitating communication between ships and shore, while promoting an HCD approach to the development of e-Navigation innovations. Articles IV-VI identified gaps and opportunities for further development in current standard operations and technologies. Yet, HCD from the micro perspective of function allocation or avoiding human-machine interaction issues is not enough. To proactively consider the impact of novel technology at a holistic level (e.g., communication networks and structures, regulations and further training and re-skilling needs of mariners, as well as aspects of workload and even cyber-security) from an early stage in the process should equally be part of the HCD process. This should not only help to improve safety and efficiency in the industry but serve as a business strategy to predict risks, prepare the domain for the change and promote technology

acceptance rather than forcingly trying to adapt to *technology push ad hoc* after implementation.

This thesis provided continuation to the author's doctoral research studies published in Costa (2016). It provides general guidelines based on the empirical studies of the appended articles and on a review of literature. These guidelines are directed at change makers and opinion leaders in the maritime domain, such as designers and developers, managers, regulators and educators (Dul et al., 2012), so that an HCD (participatory and systemic) approach can be adopted in all relevant fields of decision making to make justice to the operations and promote the success of the ongoing organizational changes that initiatives such as e-Navigation are prompting.

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