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Developing user-centred interfaces for marine navigation systems – The S-mode odyssey

Thesis for the degree *Philosophiae Doctor* (PhD)

Haugesund, March 2022

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Year:	2022
Title:	Developing user-centred interfaces for marine navigation systems The S-mode odyssey
Author:	Viet Dung Vu
Print:	Molvik Grafisk / Western Norway University of Applied Sciences

ISBN 978-82-93677-84-0

Scientific environment

This study was conducted as part of the National Joint PhD Programme in Nautical Operation, jointly administered by Western Norway University of Applied Sciences (HVL), University of Tromsø - The Arctic University of Norway (UiT), University of South-Eastern Norway (USN), and Norwegian University of Science and Technology (NTNU).

The author of this thesis was based at Department of Maritime Studies, Faculty of Business Administration and Social Sciences, Western Norway University of Applied Sciences (HVL) for the duration of this doctoral study.

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Co-supervisor: Associate Professor Marius Imset, USN Vestfold

Acknowledgements

"A journey of ten thousand miles begins with a single step"

Lao Tzu

Those are the words written on the wall of the main hall at Australian Maritime College. It is where my PhD journey began.

I believe I have travelled much more than ten thousand miles through the course of my PhD. This journey has been a long and difficult one, but I was fortunate to meet many people who have guided, inspired, and supported me, one way or another.

My deepest appreciation is given to Professor Margareta Lutzhoft, or, as I often call her, "Warchief". When I started this PhD journey, I was a sailor in unfamiliar waters on a foggy day. Everything was blur, messy, and potentially dangerous. Warchief guided me through that mess, and she is the best pilot anyone could ask for. She showed me the safe passage but let me steer the ship on my own. She acknowledged my responsibility for my ship but would intervene timely if I was about to run aground.

I would also like to thank my co-supervisor Associate Professor Marius Imset for all the excellent comments and discussions that helped me improve the quality of my work.

My gratitude to many wonderful people whom I met in the land down under. Thank you for supporting me during the first step of this journey: Dr Reza Emad, Dr Oanh Nguyen, Dr Hossein Enshaei, Dr Apsara Abeysiriwardhane, Dr Nirman Jayarathne, Capt. Asanka Rajapakse, Capt. Joakim Mansson, and many wonderful fellow PhD colleagues at Connell building.

To Dr Jonathan Earthy and Dr Gesa Praetorius, thank you for your valuable advice during my mid-term evaluation, which guided me in the right direction.

This research could not have been done without the support from many people in the maritime community. I am grateful to Capt. David Patraiko and all at the Nautical

Institute who welcomed me in London and put me in contact with many interesting people. To Mr Nick Lemon, Mr Richard Doherty, Prof. Seojeong Lee, and Prof. Min Jung, thank you so much for generously sharing your time and expertise.

My sincere thanks to the many seafarers and technology manufacturers who took part in this study. Without you, this research could not have been performed.

I am grateful to everyone here at IMS, thank you for your support and encouragement. To Vigleik, Arne, and Øystein, thank you helping me with my questionnaires and providing valuable feedback. To Bjarne, thank you for recommending many interesting books and articles. To PhD fellows Guro, Henrick, Ria, Agnes, Ole, Deepak, Meric, and Allan, thank you for all the tea and interesting conversations we had. To Johanne Marie, Helle, Hilde, and everyone else, my heartfelt gratitude for creating such a supportive work environment.

Finally, thank you, Quynh, for always being there.

Viet Dung Vu

Haugesund, March 2022

Abstract

Human factors, also known as ergonomics, is an area not properly considered when designing shipboard navigation equipment. This shortcoming results in some design issues which pose a risk to safe and efficient maritime operations. The International Maritime Organisation [IMO] has attempted to address this problem through regulatory incentive by developing new guidelines and regulations, an example of which is circular MSC.1/Circ.1609 - Guidelines for the Standardisation of User Interface Design for Navigation Equipment, also known as the "S-mode guidelines".

The S-mode guidelines introduce recommended design practices and standardise four features on the interfaces of navigation equipment. In this thesis, the development of the S-mode guidelines is analysed from two aspects, first as a design project with the design object being the interfaces of navigation equipment, and second as a joint effort from various stakeholders in the maritime industry, including the author of this thesis.

This thesis has two goals. The first goal is, through the work conducted to develop S-mode, to provide technical knowledge to support the design of future navigation equipment. The outcome of this goal includes information on the context of use for navigation equipment, usability issues to consider when using icons on navigational displays, and a recommended pattern to organise essential control functions on the interfaces of Radar and ECDIS.

The second goal is to identify contextual factors that shaped the development of S-mode and provide relevant stakeholders with recommendations to consider when developing similar future regulatory instruments. The findings suggest future design guidelines and regulations should address the requirements of both the end-users and system manufacturers. Support from influential maritime states is important to get approval at the IMO. The structure and working arrangement of the IMO do not facilitate rapid innovation and it is more realistic for aim for gradual improvements.

Future research should advance the applicability of the design recommendations introduced in this thesis by conducting studies to include functionalities of navigation systems not considered in S-mode, or by performing summative tests with high-fidelity prototypes to validate the effectiveness of those recommendations.

Also, the scope of this thesis is limited to the development of the S-mode guidelines and does not include the implementation phase. Future research, therefore, should investigate the implementation of S-mode and evaluate the guidelines' impacts on the industry.

Keywords: ECDIS, ergonomics, frequency of use, human factors, IMO, INS, icon, joint activity, logical grouping, navigation equipment, policy-making, Radar, user interface

List of publications

Paper I: Vu, V., Lützhöft, M., & Emad, R. (2019). Frequency of use – the First Step Toward Human-Centred Interfaces for Marine Navigation Systems. *Journal of Navigation*, *72*(5), 1089-1107. https://doi.org/10.1017/S0373463319000183

Paper II: Vu, V., & Lutzhoft, M. (2019). *Standard icons for control functions on navigation systems – design and issues*. Paper presented at Ergoship 2019 Conference, Haugesund, Norway.

Paper III: Vu, V., Lützhöft, M., & Imset, M. (2022). Logical grouping of data and control functions on the displays of shipboard navigation systems. *Journal of Navigation*. [paper accepted, under production]

Paper IV: Vu, V., Lutzhoft, M., & Imset, M. (2022). Developing human factors engineering guidance for marine electronics - the case of S-mode. [*paper under review at WMU Journal of Maritime Affairs].*

These articles are attached to annexes 1 to 4 of this thesis.

Additional relevant publications

Vu, V., & Lutzhoft, M. (2018). *Improving Maritime Usability - User-led Information Grouping on Navigation Displays*. Paper presented at Human Factors 2018 Conference, London.

Vu, V., & Lutzhoft, M. (2020). *Improving Human-Centred Design application in the Maritime Industry – Challenges and Opportunities*. Paper presented at Human Factors 2020 Conference, London.

List of abbreviations

ARPA	Automatic Radar Plotting Aid
BIMCO	Baltic and International Maritime Council
BLG	Sub-Committee on Bulk Liquids and Gases
CCC	Sub-Committee on Carriage of Cargoes and Containers
COMSAR	Sub-Committee on Radiocommunication and Search and Rescue
CIRM	International Association for Marine Electronics Companies
DMAIB	Danish Maritime Accident Investigation Board
ECDIS	Electronic Chart Display and Information System
e-Nav CG	e-Navigation Correspondence Group
e-Nav SIP	e-Navigation Strategy Implementation Plan
FAL	Facilitation Committee
FOU	Frequency of Use
HF	Human Factors
HFE	Human Factors Engineering
HTW	Sub-Committee on Human Element, Training and Watchkeeping
IACS	International Association of Classification Societies
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
ICS	International Chamber of Shipping

IFSMA	International Federation of Shipmasters' Associations
III	Sub-Committee on Implementation of IMO Instruments
IEC	International Electrotechnical Commission
IMO	International Maritime Organisation
IMPA	International Maritime Pilots' Association
INS	Integrated Navigation System
INTERTANKO	International Association of Independent Tanker Owners
KMOU	Korea Maritime and Ocean University
KRISO	Korea Research Institute of Ship & Ocean Engineering
LEG	Legal Committee
MAIB	Marine Accident Investigation Branch (of the United Kingdom)
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee
MSC	Maritime Safety Committee
NAV	Sub-committee on Safety of Navigation
NCSR	Sub-committee on Navigation, Communication, and Search and Rescue
NGO	Non-governmental Organisation
NI	Nautical Institute
NMA	Norwegian Maritime Authority (Norwegian: Sjøfartsdirektoratet)

OCIMF	Oil Companies International Marine Forum
PPI	Plan Position Indicator
PPR	Sub-Committee on Pollution Prevention and Response
SDC	Sub-Committee on Ship Design and Construction
SOLAS	International Convention for the Safety of Life at Sea
SSE	Sub-Committee on Ship Systems and Equipment
STCW	Standards of Training, Certification, and Watch-keeping for Seafarers
STW	Sub-Committee on Standards of Training and Watchkeeping
S-mode CG	S-mode Correspondence Group
TC	Technical Cooperation Committee
UCD	User-Centred Design
UN	United Nations

Contents

1. Introduction

Human factors, or ergonomics, is the scientific discipline that studies how humans interact with other elements in their work/life environment and applies such knowledge to improve humans' life and work. In the maritime domain, human factors has been applied in the design of ships, equipment, and procedures (Grech et al., 2008). This thesis specifically concerns the topic of human factors application in designing shipboard navigation equipment.

Improper consideration of human factors has resulted in design issues with navigation equipment that pose a risk to safe and efficient maritime operations. One reason behind the issues is the lack of guidance from regulatory bodies, particularly regarding user interface design. The International Maritime Organisation [IMO] have performed several projects to address the situation, an example of which is the development of circular MSC.1/Circ.1609 Guidelines for the Standardisation of User Interface Design for Navigation Equipment.

Circular MSC.1/Circ.1609 consists of two parts, the first part contains human factors principles to be considered when designing user interfaces for a wide range of shipboard navigation equipment. The second part prescribes four features to be applied as standard for all applicable navigation equipment, starting from January 1, 2024. These four standard features are symbols and terminologies for essential nautical concepts, the arrangement of key information/controls into groups, functions that must be quickly accessible, and default system configurations for Electronic Chart Display and Information System [ECDIS] and Radar, which are applicable for equivalent modules on Integrated Navigation System [INS] (IMO, 2019b). Despite being labelled as "Guidelines", there are clauses in circular MSC.1/Circ.1609 making parts of the document mandatory. Thus, MSC.1/Circ.1609 provides manufacturers of navigation equipment with standard ergonomic specifications to implement on their products.

The development of MSC.1/Circ.1609 represents an initiative at the IMO level to improve human factors application in developing maritime systems through regulatory incentive.

The development of MSC.1/Circ.1609 can be characterised by two aspects. Firstly, the contents of MSC.1/Circ.1609 was developed following a user-centred approach and based on empirical studies of seafarers. At the same time, the development of MSC.1/Circ.1609 was an IMO initiative with the involvement of multiple stakeholders and followed IMO working principles. In other words, the development of MSC.1/Circ.1609 was influenced by both the technical aspect of human factors application in the design of navigation systems and the political aspect associated with IMO projects.

Circular MSC.1/Circ.1609 represents an effort at the IMO level to improve human factors application in developing maritime systems through regulatory incentive. Studying factors affecting this initiative can generate useful insights for similar initiatives in the future.

This thesis, therefore, involves two themes. First, it involves the technical work done to develop the ergonomic specifications forming the core content of MSC.1/Circ.1609. Secondly, it investigates contextual factors of an IMO initiative that shaped the development of MSC.1/Circ.1609.

It should be noted that MSC.1/Circ.1609 is still known unofficially as the S-mode guidelines because it originates from a concept called "S-mode" proposed by the Nautical Institute [NI] and International Federation of Shipmasters' Associations [IFSMA] in 2007 (IMO, 2007c). For the convenience of readers, from this point onward, the two terms "S-mode guidelines" and "S-mode" will be used to refer to circular MSC.1/Circ.1609 throughout the rest of this thesis.

1.1. Research context

This study was conducted between 2018 and 2022, as a part of the National joint PhD Programme in Nautical Operations, jointly administered by four universities of Norway namely Western Norway University of Applied Sciences, University of South-Eastern Norway, Artic University of Norway, and Norwegian University of Science and Technology.

At the same time, the author of this thesis was a member of the team developing the S-mode guidelines. He was involved in the development of S-mode from 2017 until the final approval of the guidelines in 2019. However, his involvement was limited to technical work to develop contents of the S-mode guidelines. In specific, the author performed studies to identify user needs for operating navigation equipment and conducted usability tests to develop the standard features of navigation displays to be standardised by the S-mode. The author also took part in discussions that shaped the S-mode guidelines, including meetings at the IMO when the final discussions on S-mode took place. However, the author did not have decision-making power and his involvement in the decision-making process was limited to a consultative role.

Nevertheless, it can be argued that the author of this thesis wore two hats during the course of this doctoral study, one as a specialist working on a design project, and one as a researcher investigating contextual factors of a multi-stakeholder initiative at the IMO level that affected said design project.

It should be noted that, during the period of 2017-2019, the S-mode development team, to which the author of this thesis was a member, was an official correspondence group of the IMO. Members of this group was representatives from several IMO member states and organisations. However, the same group had already existed before being officialised by the IMO in 2017. For the convenience of readers, the term "S-mode Correspondence Group", abbreviated as "S-mode CG", will be used in the rest of this thesis to refer to the group of people involved in the development of S-mode, regardless of the time frame under consideration.

The following sections provide background information on human factors issues with navigation equipment and the lack of supporting regulatory instruments, before stating the aim, research questions, and objectives of this doctoral study.

1.2. Usability issues with bridge equipment

Technology advancement in the maritime field has led to the introduction of new navigation instruments onboard ships, often taking the form of complex electronic systems, or new functionalities on existing instruments. One example is the gradual replacement of paper charts by Electronic Chart Display and Information System [ECDIS] during the 2010s. While these new technologies are intended to improve safety and efficiency in navigation, their implementation can also bring adverse results when done improperly.

One of the issues is that some systems are not designed with due consideration of the abilities and limitations of users, resulting in products that are technically functional but with low usability[1]. Such systems are difficult to operate and increase the probability of erroneous actions (Mallam et al., 2015). For instance, design issues with ECDIS have been identified among contributing factors leading to several shipping accidents (MAIB, 2014, 2017; NTSB, 2014). Such issues, however, are not new problems.

As early as 2003, the IMO Maritime Safety Committee [MSC] raised concerns over design issues with existing bridge equipment. Despite the existence of performance standards, bridge systems were reported to vary greatly in terms of user interfaces and functionalities, which occurred as manufacturers introduced extra features beyond the minimum requirements to their products. This variety in interface and functionality caused difficulties for training and familiarisation, especially in time-constrained scenarios. The MSC also reported the issues of information overload and excessive alarms and called for stakeholders to consider applying human factors knowledge when developing new technology (IMO, 2003).

In subsequent years, human factors issues with shipboard equipment were reported in many academic studies (Baldauf et al., 2009; Barsan & Muntean, 2010; Krystosik-Gromadzińska, 2018; Sherwood Jones et al., 2006) and, as previously mentioned, were found among contributing factors leading to maritime accidents.

More recently, in September 2021, the Marine Accident Investigation Branch [MAIB] of the United Kingdom and the Danish Maritime Accident Investigation Board [DMAIB] published a comprehensive study on the development, training, and operation of ECDIS. The study involved observations and interviews with 155 ECDIS users onboard 31 ships of various types, supplemented by interviews with 15 pilots, 13

[1] Usability refers to the extent to which a product can be used by the intended users, under the intended context of use, to achieve the intended goals with effectiveness, efficiency, and satisfaction (ISO, 2010)

ship managers and operators, five ECDIS manufacturers, ECDIS instructors and representatives of hydrographic and technical communities (MAIB & DMAIB, 2021). The findings suggest that seafarer still face similar issues with ECDIS that the MSC identified in 2003, namely interface and menu complexities and improper alert management (IMO, 2003). The lack of standardisation in interface design was also identified as an issue, but the research participants only considered this as a minor one. The MAIB and DMAIB suggest addressing the identified issues by properly applying human factors in designing bridge equipment.

Existing literature consistently points toward the fact that there are design issues with shipboard navigation equipment, originated from improper human factors consideration during the design process.

1.3. Human factors regulatory instruments and the S-mode guidelines

There are a range of factors behind the lack of human factors consideration in the design of bridge equipment. One factor is the traditional engineering-centric approach in designing ships and shipboard equipment and a design is considered mainly from technical and economical viewpoints (Lützhöft et al., 2017).

Another factor is the fact that people leading design projects often do not have the knowledge of nautical operations and do not understand the requirements of the end-users, who are seafarers (Chauvin et al., 2008). Furthermore, the knowledge and perspectives of seafarers are often not considered in a design, seafarers are rarely involved in the design process, and there is no effective channel of communication between designers and seafarers (Vu & Lutzhoft, 2020).

Regulatory instruments from maritime administrators also do not provide adequate guidance to designers. Analyses of regulations and guidelines on human factors in the design of bridge and bridge equipment find a lack of detailed descriptions for interface design (Mallam & Nordby, 2018). As the maritime industry is working toward digitalisation with an objective of increased automation in shipping, it is expected that future bridge equipment will become more complex. Under these circumstances, there are both opportunities and necessity to develop regulations/guidelines or amend existing ones to improve usability and design consistency for navigation equipment.

1.4. Research aim

The aims of this study are twofold. Firstly, it provides technical knowledge to support the design of future shipboard navigation systems with usability in mind. Such technical knowledge includes:

- Information on how seafarers operate different functions of bridge equipment when engaging in navigation duties
- A recommended pattern to organise essential contents into groups on the displays of Radar and ECDIS or their equivalent modules on INS
- Usability issues to consider when using icons on the interfaces of navigation systems to convey messages of information or control functions

These technical data are the results of the author's work during his time as member of the S-mode CG.

The second aim of this study is to understand factors that were influential behind key events that shaped the development of the S-mode guidelines. The term "key event" refers to any event and decision occurred during the development of S-mode that led to the establishment of or changes to at least one of the followings: the status of S-mode as an IMO project, the scope of S-mode, or the content of S-mode.

The specific objectives derived from this goal are as follows:

- Identifying key events that shaped the development of S-mode
- Identifying factors affecting key events during the development of S-mode, considering the technical aspect of S-mode as an international multi-stakeholder design project with the design object being the interfaces of shipboard navigation system
- Identifying factors affecting key events during the development of S-mode, considering the political and organisational aspects of S-mode as an IMO project

As discussed in previous sections, there are currently human factors issues with shipboard navigation equipment, resulted from the inadequacies of design guidelines and regulations. The first aim of this study serves as a short-term solution to these issues by supporting equipment manufacturers with technical recommendations. The second aim serves as a long-term solution by recommending regulatory agencies, particularly the IMO, important factors to considered to effectively develop regulatory instruments similar to the S-mode guidelines in the future.

1.5. Thesis structure

This thesis is organised in eight chapters. The following **chapter 2** provides a background of the IMO, procedures for developing international maritime regulations, and relevant earlier studies. **Chapter 3** introduces joint activity as the theoretical framework for this study. **Chapter 4** presents the research methodology, describes procedures for data collection and analysis, and discusses methodological rigour.

Chapter 5 describes key events from the emergence of the S-mode concept to the point when the scope of the S-mode guidelines was finalised. **Chapter 6** provides details of the studies conducted to develop, evaluate, and finalise the four standard features on the interfaces of navigation system forming the core of the S-mode guidelines.

Chapter 7 presents an analysis of key events that occurred during the development of S-mode using the framework of joint activity and identifies contextual factors that shaped the S-mode guidelines.

Chapter 8 concludes the thesis, presents recommendations for relevant stakeholders, and provides implication for future research.

2. Background

This chapter provides an overview of the objectives, functions, and institutional structure of the IMO, followed by a description of principles for IMO rule-making process together with the involved actors. The development of the S-mode guidelines is then introduced, and the chapter concludes with an overview of relevant earlier studies.

2.1. IMO – objectives, functions, and institutional structure

The IMO is the specialised agency of the United Nations [UN] responsible for regulating international shipping, with the objectives of promoting safe, secure, and efficient shipping and protection of marine environment (IMO, 2013). The functions of the IMO, as stated in Article 2 of the 1948 Convention on the International Maritime Organisation, are drafting conventions, regulations, and other suitable regulatory instruments, providing machinery for discussions and negotiations among Members, and making recommendations on related matters. The primary function is drafting and amending regulatory instruments within the assigned scope and the Organisation is today responsible for some 50 international conventions and protocols and more than 1000 codes and recommendations (IMO, 2013). As of January 2022, the IMO consisted of 174 Member States and three Associate Members (IMO, 2022). The IMO also grants consultative status to a number of non-governmental organisations [NGO] (IMO, 2021b).

The institutional structure of the IMO has changed overtime and, currently, the Organisation consists of an Assembly, a Council, and five main Committees, which are supported by a number of Sub-Committees. Figure 1 provides an overview of IMO structure:

The overall administration of the Organisation is performed by the Secretariat, which consists of a Secretary General and about 300 supporting international personnel (IMO, 2021c). Functions of the Secretariat include preparing for meetings, collecting and distributing documents, drafting reports and working papers, and publishing IMO publications (Campe, 2009).

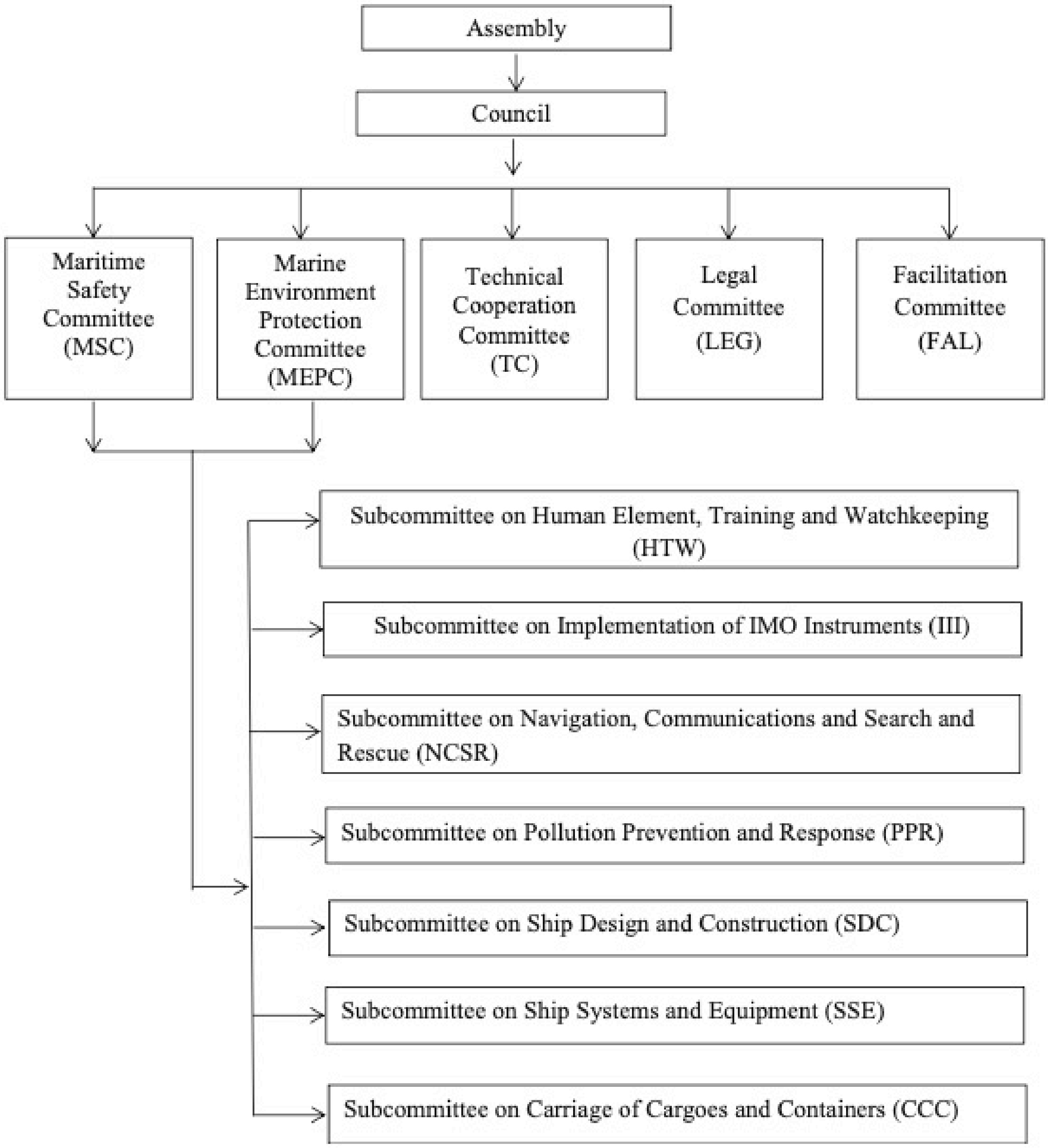

Figure 1. IMO institutional structure (Karim, 2015)

The Assembly is the governing body of the IMO and responsible for approving the working programme and financial arrangements. All Member States are included, and meetings are held biennially, although extraordinary sessions may occur if necessary. The Assembly elects the Council, which acts as the executive body of the Organisation and consists of 40 members. The main function of the Council is to supervise the work of the Organisation and it performs the same functions of the Assembly during the time between Assembly sessions. The only exception is the function to make recommendations to Governments on maritime safety and pollution prevention, which is reserved for the Assembly. The 40 council members are grouped into three categories. Category A consists of states with the largest interest in providing international shipping services. Category B consists of states with the largest interest in international seaborne trade. Category C consists of states not belonging to the other categories but have special interests in maritime transport or navigation and their election ensure the representation of world major geographic areas (IMO, 2021c).

IMO missions are carried out by five committees. As illustrated in Figure 1, the five committees are: Maritime Safety Committee [MSC], Marine Environment Protection Committee [MEPC], Technical Cooperation Committee [TC], Legal Committee [LEG], and Facilitation Committee [FAL]. All members have membership in these five committees. The MSC and MEPC are also supported by seven sub-committees:

- Sub-committee on Navigation, Communication, and Search and Rescue [NCSR]
- Sub-Committee on Ship Design and Construction [SDC]
- Sub-Committee on Ship Systems and Equipment [SSE]
- Sub-Committee on Human Element, Training and Watch-keeping [HTW]
- Sub-Committee on Implementation of IMO Instruments [III]
- Sub-Committee on Pollution Prevention and Response [PPR]
- Sub-Committee on Carriage of Cargoes and Containers [CCC]

Similar to the main committees, all sub-committees are open to all members. Both committees and sub-committees are involved in policymaking. The committees deal with high-level decisions while sub-committees consider detailed technical matters, assigned to them by the parental committees. Results from the sub-committees are reported back to the relevant committee for consideration and these results are the basis for decisions at the committee level (Svensson, 2014).

As the highest technical body of the IMO, the MSC considers any matter that directly affects maritime safety, which includes the construction and equipment of vessels and other HF-related issues. The development of the S-mode guidelines was under the agenda of the MSC. The detailed technical works were coordinated by the NCSR. As previously mentioned, the IMO structure changes over time and during the development of the S-mode guidelines, the coordination task was first assigned to the Sub-Committee on Safety of Navigation [NAV] until NAV was merged with the Sub-Committee on Radiocommunication and Search and Rescue [COMSAR] to form NSCR in 2014.

2.2. The development and amendment of IMO instruments

The IMO law-making process is strictly regulated with certain steps to be followed. The work for developing new IMO instruments or amending existing ones starts with a proposal from Member States to a relevant IMO organs (IMO, 2021a). Proposals can also be made by NGOs with co-sponsorship from Member States. The proposals must contain compelling arguments to justify alignment with the Strategic Plan of the Organisation and the necessity of IMO actions. If accepted, the proposal will be incorporated into the current or future working programme of the committees, with descriptions of the technical work to be undertaken, responsible sub-committees, and target completion dates (IMO, 2015c).

Committees and sub-committees consider relevant matters and make decisions during plenary sessions, which are held at the IMO headquarters with the participant of all delegates. Depending on the working agenda, the committees and sub-committees can establish working and drafting groups. Working groups are tasked with considering unsettled technical matters while drafting groups are tasked with editorial work to finalise the draft of decided regulatory instruments (Svensson, 2014). These groups meet simultaneously and use English as the working language without interpretation. Such arrangements make it difficult for countries with small delegations to attend all groups and also pose some restrictions to non-English-speaking delegations. Acknowledging this problem, the IMO restricts the number of groups to be no more than five during a plenary session and recommends against forming intersessional working groups (Tan, 2005).

Based on the author's observation while participating at NCSR 6[2] in 2019, informal negotiations existed alongside official discussions and significantly affected the final decisions. Each working day was divided into a morning and an afternoon period with a two-hour lunchbreak in between. The morning was spent to declare the matters to be discussed for the day and decisions would be made in the afternoon. A lot of talks and agreements happened during the lunchbreaks and delegates with aligned interests formed coalitions to assert influence over the final decisions. However, these informal negotiations were not recorded in official reports. Also, many negotiations and agreements had already taken place before the meetings started. Svensson (2014) made similar observations while attending BLG 15[3] in 2011 and MEPC 66[4] in 2014.

Besides working and drafting groups, it is also possible to form correspondence groups to facilitate the consideration of an issue. A correspondence group can work intersessionally under the coordination of a lead country or organisation and members often participate remotely via emails or similar communication platforms. Correspondence groups' results are submitted to the forthcoming session of the parental committees or sub-committees. The IMO also limits the number of correspondence groups to be no more than three under normal circumstances (IMO, 2008a).

Once completed with the assigned technical work, the responsible sub-committees report back to the parental committees, who will then make policy decisions based on these reports. Decisions are made by voting at the committees, council, or assembly with the exact procedures provided in the rules of procedures for respective IMO organs.

2.3. Actors in the making of IMO regulatory instruments

Member states are the actors with decision-making power at the IMO. The Organisation also collaborates with other UN agencies and intergovernmental

[2] The sixth session of the NCSR, participated as a member of the Nautical Institute [NI] delegation

[3] The 15th session of the the Sub-Committee on Bulk Liquids and Gases [BLG]

[4] The 66th session of the MEPC

organisations on relevant matters, but such organisations do not have direct decision-making power at the IMO. Similarly, NGOs with consultative status do not have voting rights at IMO meetings. However, both intergovernmental organisations and NGOs can influence IMO decisions, either through collaboration with the Organisation or through their members, who are also IMO member states.

As established in the Convention on the International Maritime Organisation, unless when failing to fulfil their financial obligation to the Organisation, member states are given equal voting right. In practice, however, member states have unequal decision-making power (Argüello, 2021). Given the different and sometimes opposing interests among members, IMO negotiations can be characterised as political contests between states (Svensson, 2014). Member states' influence over an IMO decision depends on two factors: their willingness to enter the negotiation, and the resources they can commit to pursue favourable decisions.

The willingness of a state to enter an IMO negotiation depends on whether the issue being negotiated concerns the state's national interests. For instance, the adoption of the International Convention on Standards of Training, Certification, and Watch-keeping for Seafarers [STCW], 1995 (STCW 95) was supported by two main groups of member states with strong interest in improving competency for seafarers. The first group consisted of states whose merchant fleets largely employ foreign seafarers and would benefit from improved safety of their ships, resulting from an improved worldwide seafarer training standard. The second group consisted of major suppliers of manpower for the world's merchant fleet. These countries would benefit from technical and financial assistances from countries employing their seafarers to improve the quality of maritime education. As a result, both these two groups of member states participated actively in the review of STCW 78 and the subsequent adoption of SCTW 95 (Dirks, 2004).

Besides national interest, a member state's influence is affected by the resources committed to strengthen its stand at the Organisation. In this regard, there is a significant division between developed and developing countries. Developing countries often do not have resources to send large delegations and, therefore, are not represented in all IMO sessions. Also, these states often lack the technical expertise to understand and form an opinion on the issues under consideration. Developed countries, on the other hand, have both the technical expertise and the capacity to send large delegations to the IMO and guarantee their representation in IMO meetings at all levels. Furthermore, many delegates from developed countries have attended IMO meetings for many years and have substantial personal influence over IMO proceedings. As a result, developed countries often have superior power over IMO decisions (Svensson, 2014). It should be noted that the two terms “developed” and “developing countries” used in this section only have arbitrary meaning and countries such as China, India, or Russia, which are categorised as Developing Economies (IMF, 2021), do have a strong influence at the IMO. These terms only denote a country’s ability to commit financial and human resources to influence IMO negotiations, which can be determined by factors such as the size of national economy, size of the national fleet through ownership and/or registry, membership in the IMO council, and personal influence of individual delegates (Tan, 2005).

2.4. The development of the S-mode guidelines

The topic under study of this thesis is the development of MSC.1/Circ.1609 – the S-mode guidelines, which started in 2007 and completed in 2019. This section briefly summarises key events associated with the development of the S-mode guidelines.

The S-mode guidelines began with the introduction of a concept called “S-mode” by the International Federation of Shipmasters’ Associations [IFSMA] to NAV 53 in 2007 (IMO, 2007c). The IFSMA raised the issue of variety in interface design between manufacturers of navigation systems, which caused difficulties for training and familiarisation especially under time-constraints such as in the case of maritime pilots boarding new ships. To address this issue, the IFSMA called for the introduction of a standard interface mode for all navigation displays. This standard interface mode, called “S-mode” would be activatable by a single operator action (IMO, 2008b). The development of S-mode was proposed as an additional output to an existing IMO initiative called “e-Navigation”[5]. NAV 53 did not endorse the concept as it was

[5] E-Navigation is an initiative of the IMO, aiming to regulate the development and implementation of modern information technology in shipping (Hagen, 2017).

considered immature but recommended IFSMA to continue developing the concept and update the sub-committee with the progress (IMO, 2007d).

Between 2008 and 2013, there was limited development of the concept of S-mode and negotiations were focused on getting S-mode accepted as a part of e-Navigation. Since the introduction of the concept, there had been two main opinions among IMO members and NGOs, one supporting and one disapproving of S-mode. In NCSR 1 in 2014, there was a major challenge to the status of S-mode among e-Navigation outputs and a voting was conducted to decide whether S-mode should be retained among the e-Navigation solutions. The outcome of the voting supported the retainment of S-mode in e-Navigation agenda. S-mode officially became an output of e-Navigation after being approved by the MSC during their 94^{th} session (IMO, 2014a).

In 2015, an informal correspondence group was formed to work on S-mode, led by Australia. This correspondence group was "informal" since the number of correspondence groups at the time had reached the limit as prescribed by the Organisation and it was not possible to establish another official correspondence group. Nevertheless, this informal correspondence group functioned as an official one. The main task of the group was to determine an exact scope of S-mode, specifically which equipment was to be implemented and what exactly would be standardised. The group could not develop a scope of S-mode agreeable to all parties involved and no progress was achieved during 2015-2016. However, the group did conduct several studies to understand user behaviour during work with shipboard navigation systems.

A breakthrough came in 2017 when the CIRM proposed a new scope of S-mode that, instead of standardising the entire interfaces, would only standardise certain features of the interfaces including symbology, terminology, arrangement of key control functions, quickly accessible functions, and default system configurations. This proposal gained support from the majority of stakeholders and was subsequently approved as the official scope of S-mode in NCSR 5 (IMO, 2018a). The informal S-mode correspondence group was officialised and tasked with developing contents for the S-mode guidelines, based on the established scope.

The work during 2018 was to develop and finalise the contents of the S-mode guidelines through conducting usability studies and applying results of previously conducted user studies. The finalised draft of the S-mode guidelines was submitted to NCSR 6 for consideration. NCSR approved the draft with minor adjustments and the guidelines were subsequently adopted at MSC 101 as circular MCS.1/Circ.1609.

2.5. Relevant earlier studies

To the author's knowledge, there has not been any previous study on the development of HF policies and regulations in shipping. A reason is because the topic of human factors itself only recently entered the maritime domain, first considered by the IMO in the early 1990s following the loss of the Herald of Free Enterprise (Kim, 1997). Since then, IMO's discussions on HF have led to major outcomes such as the Organisation's strategy to address the human element (IMO, 2006a) and the 2010 Manila amendments to STCW Convention. However, the introduction and implementation of HF-related policies and regulations by the IMO is characterised by a slow pace of advancement and a disconnection with academic studies. Schröder-Hinrichs et al. (2013) conducted a review of HF-related research articles published between 1973 and 2012 in the Journal of Navigation (380 articles) and Maritime Policy & Management (133 articles) as well as HF-related documents submitted to the MSC between 1985 and 2012 (2158 documents). Their results suggest that the consideration of HF-related matters at the IMO is affected by the infrequent interval of IMO meetings at all levels, which reduces the speed of decision-making. Additionally, academic findings are not properly applied in IMO decisions and results of academic work are mainly used to justify arguments at IMO meetings (Schröder-Hinrichs et al., 2013).

Although the development of IMO HF-related policy is not a well-studied topic, there is a large body of literature on IMO regulatory instruments concerning training standards for seafarers and environmental protection. These studies can be used as references to factors affecting decision-making at the IMO during the development and/or amendments of regulatory instruments.

Considering standards of training for seafarers, Dirks (2004) analysed the decision-making process behind STCW 95. Similar to the work on marine pollution preventions policies previously discussed, the work on STCW 95 can also be characterised as series of discussions and negotiations between IMO member states and NGOs. Dirks (2004) focused specifically on the way involving parties resolve their conflicts of interest and provided an explanation through two theoretical approaches: rational choice and social constructivism. With the rational choice approach, Dirks (2004) identified aspects of the adoption of STCW 95 that benefits the member states and NGOs. Using a social constructivism approach, Dirks (2004) described factors shaping the interests and behaviours of the involved parties. Combining the two approaches, this work suggests that STCW 95 was made possible by a group of influential IMO members who could negotiate and align their overlapping interests with the adoption of STCW 95. While the topic is different, the context of this study is similar to S-mode and the findings provides relevant insights into decision-making processes at the IMO.

Regarding environmental protection policies, Svensson (2014) studies the reasons behind the selection of a regional approach instead of a global one in implementing SO_x Emission Control Areas. The findings suggest that the stakeholders involved in decision-making were divided into two groups, one supporting the global approach and the other supporting the regional approach. The final decision was made based on an agreement between the two groups as there was insufficient scientific data to make a conclusive policy decision. Both groups used incomplete scientific data to justify their arguments with underlying economic motives. Decisions were strongly connected to the economic interests of the involved decision makers and NGOs had a significant influence in shaping the policy, particularly the Oil Companies International Marine Forum [OCIMF]. An earlier study by Tan (2005) provides an overview of the actors and activities behind environmental protection regulations in shipping until 2006. The study also analyses the decision-making process that led to the adoption of Annex VI of International Convention for the Prevention of Pollution from Ships [MARPOL]. Similar to the work of Svensson (2014), this study also suggests that similar conflicts of interest and the political dynamics among IMO members and NGOs shaped decisions at the IMO.

In summary, earlier studies on the development of IMO regulatory instruments consistently point toward the conflicts of interests and political influence of members as having significant impact on shaping IMO policies. The actual actors involved, their interests and decision-making power, however, differ between contexts.

3. Joint activity as the theoretical framework

In this doctoral study, the interaction and collaboration between IMO members and organisations in the development of the S-mode guidelines is viewed through the concept of joint activity introduced by Clark (1996). This chapter discusses major characteristics of the joint activity concept and how the concept is applicable for the topic under study.

3.1. The concept of joint activity

The concept of joint activity was defined by Clark (1996) as any activity with more than one participant, where the participants coordinate to reach common goals and their actions are interdependent. In his work, Clark (1996) uses the concept to explain how people use language in communication. However, Clark (1996) based his definition of joint activity on Levinson (1979)'s notion of "activity" as any culturally recognised activity whether or not any use of languages is involved. Thus, the concept of joint activity can be used to describe an activity in any domain, as long as such activity satisfies the criteria to be considered a "joint" one.

The following section discusses the prerequisites of a joint activity and how the efforts from involved stakeholders in developing the S-mode guidelines can be considered a joint activity.

3.2. Common goals and Interdependence between participants

From the definition, it can be deduced that a joint activity is only formed when at least two participants agree to work together to achieve certain goals. Such an agreement is termed "Basic Compact" and represents the level of commitment for all parties to be a part in the joint activity (Klein et al., 2005).

An important aspect of the Basic Compact is the commitment of the involved parties to align their individual interests to a certain degree to form common goals (Klein et al., 2005). Participants in a joint activity often purse multiple goals at once. Clark (1996) categorises goals into public and private goals. A public goal is a goal made aware to all participants, either through official announcements or tacit acknowledgements. A private goal, on the other hand, is hidden from view and known only to the concerned participant. Common goals in a joint activity must be public.

Having common goals does not mean all participants in a joint activity follow the same agenda. More often, each party has individual goals, which can be either public or private. In some cases, individual goals of each party can conflict with each other. Under such circumstances, collaboration can only be achieved if the parties are willing to take actions to find alignments between their individual goals to create common goals.

In the case of S-mode, from the official introduction of the concept in 2007 to the point before S-mode became an official e-Navigation solution following MSC 94 in 2014 (IMO, 2014a), there was no common goal among the involved parties. However, after S-mode officially became an item on the agenda of e-Navigation, the involved stakeholders managed to have common goals. The first was to determine a scope of S-mode, and the second was to develop the contents of the S-mode guidelines.

Another prerequisite of joint activity is the interdependence between the involved parties. Clark (1996) argues that, in a joint activity, the actions of one party must have certain impacts on the actions of other parties and vice versa. If the actions of parties to an activity have no influence on each other, such an activity is not considered a joint activity but a parallel activity.

As an IMO initiative, the work to develop S-mode has, since the beginning, been a series of negotiations and agreements between IMO member states and organisations. There were always arguments and counter arguments, and actions of one stakeholder significantly affected actions of others, even when there was no common goal.

Considering both criteria, it can be argued that the later phases in the development of the S-mode guidelines fit the criteria of a joint activity. The absence of a common goal at the beginning means there was no joint activity at the earlier phases in the development of S-mode. However, the model of joint activity is still applicable to explain events during these earlier phases. Specifically, it helps explain the presence of conflicting individual goals and how the participants subsequently compromised and created common goals.

With the formation of a joint activity, there are factors that facilitate or hinder the collaboration between participants. The following section discuses facilitators in a joint activity.

3.3. Facilitators in joint activity

Effective coordination in a joint activity requires the participants to be able to predict the actions of others, share a common perspective, and direct each other to adapt to changes in the situations (Klein et al., 2005). This section discusses factors facilitating effective coordination in joint activity: interpredictability, directability, and common ground.

3.3.1. Interpredictability and Directability

Both interpredictability and directability are important factors in coordination. Directability refers to the ability of participants to direct actions of each other to adapt to situational changes during the course of a joint activity (Christoffersen & Woods, 2002). Directability is important for building resilience in team collaboration. Interpredictability refers to the ability of a participant in a joint activity to predict the actions of other participants with a reasonable degree of accuracy (Klein et al., 2005). In combination, interpredictability and directability allow participants to establish and maintain effective collaboration. Both factors can be improved by several means.

One way to improve interpredictability is by having a formal action plan shared between participants. In such a way, participants have an expectation of the actions of others. Additionally, predictability is significantly improved when participants can take on the perspective of others.

[In the case of S-mode, this phase of the joint activity could be said to have started in 2015. At this point the work plan of the S-mode CG acted as the script to let the involving parties be informed of the work to be performed by each member].

3.3.2. Common Ground

The most important basis to for effective collaboration is a common ground, which is defined as mutual knowledge, mutual beliefs, and mutual assumptions shared among members of a joint activity (Clark & Brennan, 1991). It is this shared foundation that allows participants to predict and direct each other's actions.

Common ground is not static but rather constantly develops as participants communicate, update and repair their mutual understandings throughout the course of a joint activity (Brennan, 1998). At any moment, the common ground can be characterised by three elements: initial common ground, current state of the activity, and public events so far. Initial common ground refers to background facts and assumptions forming the presuppositions of each participant when entering the joint activity. Current state of the activity refers to the participants' presuppositions of what is currently occurring within the joint activity. Public events so far are presuppositions of what public events have occurred since the beginning up to the current point of the joint activity (Clark, 1996).

The term "presupposition" is used here to emphasise that people do not always know all the constituents of the common ground. In other words, participants in a joint activity cannot always be certain of exactly which information and what beliefs they mutually possess at a given time. Each participant has a personal version of what he or she believes to be the common ground and that is what they act upon. As a result, discrepancies sometimes occur and can hinder collaboration. In such cases, the participants need to carry out "repairs" to realign their common ground.

It is common for participants in a joint activity to have different perspectives due to differences in background, experience, and circumstances. As such, it is common for discrepancies in perceiving common ground to emerge and it is argued that correcting such discrepancies requires participants in the joint activity to negotiate and resolve their differences, effectively improving the quality of collaboration (Feltovich et al., 1996).

In the case of S-mode, an initial common ground existed before the emergence of the S-mode concept in that all IMO members and organisations had an experience of IMO work. As a result, IMO members and organisation share knowledge on IMO working principles. When the S-mode concept was first introduced in 2007, descriptions of the original S-mode concept were added to the shared knowledge between IMO members and organisations. However, it can be argued that a common background did not exist or exist at a very weak form at this point as people viewed S-mode very differently and there was limited exchange of information. As mentioned in section 3.2, S-mode officially became an e-Navigation following MSC 94 in 2014, and this was the moment when people started building an updated common ground. This common ground constantly evolved throughout the course of developing S-mode. Discrepancies did arise and participants had to take corrective actions to realign their perceptions of the common ground. Chapter 7 provides a discussion on common ground shared between members of the S-mode CG.

4. Methodology

As discussed in section 1.1 on the context of this doctoral study, the author of this thesis assumed two identities during the research process, first as a member of the S-mode CG from 2017 until NCSR 6 in January 2019, and subsequently as a researcher studying the S-mode development process from February 2019 to 2022. This study was organised in two phases, corresponding with the duration of these two identities. Each phase served one of the two research objectives discussed in section 1.4 and employed different sets of methods.

This chapter describes the methods used in each research phase and discusses the rationale behind the selection of methodology for this study. The chapter is organised in two main sections, each addressing one of the two research phases.

4.1. Phase 1 - Usability studies to develop S-mode

The main contents of the S-mode guidelines are four standard features for the interfaces of shipboard navigation systems: icons & terminologies, grouping of key control functions, functions that must be quickly accessible, and default system settings. These standard features were developed following the principles of user-centred design, specifically following the guidance provided in standard ISO 9241-210 (ISO, 2010).

User-centred design [UCD] is a design approach that bases the design upon an explicit understanding of users, the tasks to be performed, and the intended working environment. Following UCD principles, the design is developed and refined by user-centred evaluation and the whole design process is iterative. Figure 2 illustrates the interdependence of activities in a user-centred design process.

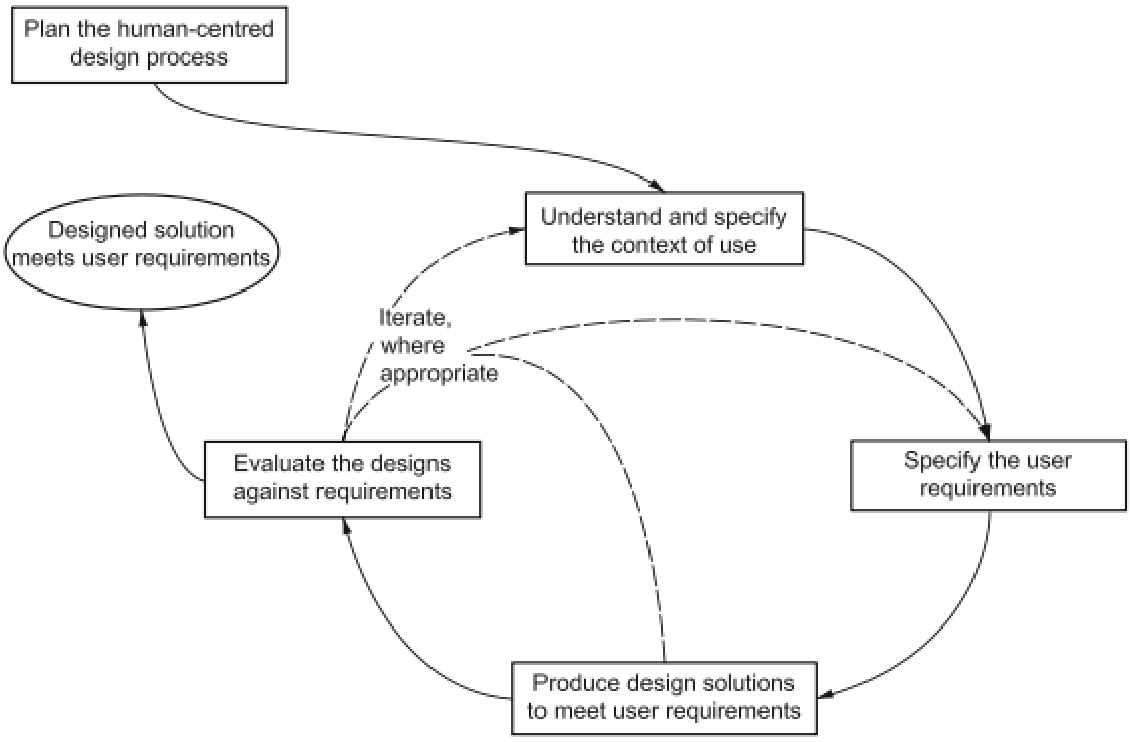

Figure 2. User-centred design activities (ISO, 2010)

A major activity in a UCD process is studying user needs to specify the requirements for the system being designed. In the case of S-mode, this step was done by several user studies conducted by members of the development group. The author of this thesis was responsible for three studies.

The first study was a review of cognitive analyses of marine navigation tasks. The aim of this study was to identify which tasks a mariner perform when engaging in navigation duties, and which functions of bridge equipment are required to support mariners in doing their jobs. The author has originally planned to perform a new task analysis but changed the plan after considering two factors. Firstly, there have been several analyses of navigation tasks done both in academia and in the industry, and all of them have limitations. Secondly, conducting a new comprehensive analysis is time- and resource-consuming, even more so if the author would attempt to avoid the limitations of previous analyses. As a result, the author decided not to conduct a new analysis, but rather to review existing analyses, accommodate their shortcomings, and combine the results. Given the advancement of navigation techniques over time, the analyses done by Sanquist et al. (1994), Røed (2007), Procee et al. (2017), Van Westrenen (1999), and Koester et al. (2007) were considered. The author took the following measures to address the shortcomings of these analyses:

- The analyses were conducted over a long period of time. As a result, some of the identified tasks reflect out-dated practices, many of which have been automated or modified. To address this issue, the research team identified such out-dated practices and updated them using literature on contemporary nautical practices (IMO, 2004, 2006b, 2007b; Swift, 2004) and the experience of the researchers, all of whom were seafarers. An example is the task of computing Target Relative Motion and True Motion Vectors by plotting on the Radar Plan Position Indicator [PPI], as described in the analysis by Sanquist et al. (1994), which has long been automated by Automatic Radar Plotting Aid [ARPA].

- Many existing task analyses have a limited scope, such as area of observation, people observed, or having specific operational contexts such as high-speed crafts (Røed, 2007). To address this issue, the author identified such specific tasks and removed or adapted them to conventional navigation scenarios. This step was taken using two sources of reference. The first one is literature on contemporary nautical practices and the experience of the author and colleagues who were previously deck officers on merchant ships. The second source is the results of the survey on Frequency of Use [FOU] for standard functions of INS, which will be discussed in subsequent sections.

- All existing analyses lack details in some of the identified tasks while giving sufficiently detailed descriptions for others. To address this issue, the research team merged all analyses together, allowing the merits of one analysis to accommodate for the shortcomings of another. Results of the FOU survey were also used to add details to under-specified tasks.

The second study was a review of mandatory functions that must be available on Radar, ECDIS, and INS. The author reviewed performance standards for Radar, ECDIS, and INS and listed mandatory functions.

The third study was a survey on the frequency of which seafarers operate each of the mandatory functions of an INS. The survey was distributed online with the support of the Nautical Institute. 601 seafarers took part in the survey, rating the frequency of use for each function and describing the purposes and scenarios of use. The results identify functions that are most frequently used and provides more insights into the usage pattern of navigation equipment. Results of this study are included in Paper I (Vu et al., 2019), attached to Annex 1 of this thesis.

In combination, the three aforementioned studies helped establish an overview of the way seafarers operate navigation equipment and guided the development of the S-mode guidelines, particularly the four standard interface features. As illustrated in Figure 2, once the context of use and user requirements are identified, the next step in a UCD process will be to develop design solutions to address user requirements within the defined context of use. In the case of S-mode, it was the CIRM who developed the first edition of the four standard interface features and they introduced this edition during the 2017 e-Navigation underway Asia-Pacific conference in Jeju, Republic of Korea (IALA, 2017). Details of this first edition are included in the first complete draft of the S-mode guidelines, approved in NSCR 5 (IMO, 2017a).

Following a UCD approach, this first edition of the four standard interface features must be tested to evaluate the extent to which it satisfies user requirements. To this end, the S-mode CG conducted several usability studies. The author of this thesis was responsible for two usability studies, the details of which are summarised in Table 1. It should be noted that these two studies only contribute a part of the work done by the S-mode CG to develop and finalise contents for the S-mode guidelines. Presenting full details of these studies without disusing the work done by other members of the S-mode CG would be out of context. As a result, this section will only provide a summary of these two usability studies together with links to relevant references in Table 1. Section 6.3 will discuss these studies together with the work done by other members of the S-mode CG in more details.

Table 1. Usability studies conducted by the author during the development of the S-mode guidelines

Usability study	**Objectives**	**Number of participants**	**References**
Icon usability tests	Test the recognisability of 59 icons representing essential functions and information on navigation equipment	424 seafarers	Details of the test methods and parts of the results are presented in Paper II (Vu & Lutzhoft, 2019), attached to Annex 2 of this thesis Full results of the tests are presented as a technical report, submitted to the S-mode CG. A copy of this report is attached to Annex 7 of this thesis
Logical grouping of essential functions	Develop a pattern to group essential contents on the display of navigation equipment	63 seafarers in the formative study 35 seafarers in the summative study	Results submitted to the Journal of Navigation, accepted and currently under production. Details are presented in Paper III (Vu, Lutzhoft, et al., 2022b), attached to Annex 3 of this thesis

Phase 1 of this study concluded when the S-mode guidelines was officially adopted by the MSC in 2019. From that point onward, this doctoral study entered the second phase with the objective of identifying contextual factors that influenced the development of the S-mode guidelines.

By participating in the development of the S-mode guidelines, the author developed a thorough understanding of the technical aspects of S-mode and established a collaborative relationship with representatives of major stakeholders. Through this involvement, the author had access to a wide range of documentation including reports and papers issued by and submitted to various IMO organs and associate organisations as well as internal discussions among members of the team developing the S-mode guidelines. This background played an important role in deciding a research approach for the 2nd phase of this study.

In the following sections, the author will discuss the rationale behind the choice of a case study approach for the 2nd research phase and provide a detailed description of the procedures followed.

4.2. Phase 2 - A case study on the development of S-mode

The choice of research methodology is influenced by the research context and guided by the research aim(s), epistemological concerns, and norms of practice of relevant work in the research area (Buchanan & Bryman, 2007).

To select a suitable methodology for the 2nd phase of this doctoral study, the most important factor to be considered was the research objective of understanding contextual factors that shaped the development of S-mode, particularly the interactions between stakeholders with different agendas and decision-making power. Achieving this objective requires a clear understanding of context and the inclusion of the multiple perspectives of the involving stakeholders. Understanding of context is a prerequisite to see an action through the perspective(s) of the actor(s) and to provide explanations to such action (Mason, 2002). The inclusion of stakeholders' multiple perspectives is also important to achieve the desired level of comprehensiveness and improve the validity of the findings.

Case study is a qualitative methodology suitable for providing a holistic, in-depth understanding of social phenomena in the natural context and is capable of bringing out details from the multiple viewpoints of the involving stakeholders (Johansson, 2007; Tellis, 1997a; Yin, 2009). Case study methodologies have been employed in studying similar topics, such as the adoption of STCW 95 (Dirks, 2004) or the development of the Convention on Long-range Transboundary Air Pollution (Lidskog & Sundqvist, 2002).

Considering the aforementioned factors, the decision was made to adopt a case study methodology for this 2nd phase of the doctoral study, specifically following the instrumental framework. In an instrumental case study, it is not the main priority to understand the case itself but rather, through an understanding of the case, providing insights into an external matter, which could be an issue that needs to be addressed or a theory requiring refinements (Stake, 1995). In other words, the case under study is of secondary interest and serves a supporting role, enabling the researchers to understand the external interest. To serve this supporting role, the selected case would be looked at in depth, with detailed analysis of the underlying contexts and involved activities. In this thesis, the case of interest is the development of the S-mode guidelines, with the underlying goal of explaining the lack of human factors consideration in designing bridge equipment through a regulatory viewpoint.

An important question to consider when conducting case studies is the choice between the single-case and multiple-case approach. Meyer (2001) suggests a multiple-case approach is more desirable to a single-case approach due to the advantage of enhanced external validity and reduced observer bias. The study of multiple cases, each with its own context, allows the researchers to analyse and compare across contexts and generalise theories. Flyvbjerg (2006), however, challenges this view and argues that an in-depth study of a single case can generate knowledge valid beyond the local context, especially when used for falsification testing. The author of this thesis supports both views and believes a multiple-case approach should be followed if applicable while, at the same time, also acknowledges the contribution of single-case studies in generating and expanding scientific knowledge. This study follows a single-case approach as a pragmatic choice. Case selection in multiple-case studies aims for information richness rather than randomisation as in the case of statistical sampling and often aims for cases of polar types (Eisenhardt, 1989). Following a multiple-case approach requires access to data of multiple cases with comparable levels of detail, which was not practical under the circumstances of this doctoral study. On the other hand, with the single-case approach, the author had access to a large amount of data on the development of the S-mode guidelines from multiple sources. As a result, a single-case approach was selected, and measures were taken to address the weaknesses of single-case approach.

The following sections explain the procedure for this 2nd research phase, including methods for data collection and analysis.

4.3. Planning and conducting the 2nd research phase

To address the weaknesses of the single-case approach previously discussed, this study employs an embedded design, treating the perspectives of each major stakeholder in the development of S-mode as a separate unit of analysis. Using sub-units within a larger case allows the analysis of data within each sub-unit and comparison across sub-units, similar to within case and cross cases analysis in a multiple-case approach (Baxter & Jack, 2008). In specific, the viewpoints of each major stakeholder involved in developing S-mode were collected and compared with each other, and special attention was given to conflicting ideas and recollections. Furthermore, the study employs triangulation of data and investigators.

Triangulation of data was achieved by using multiple data sources. The second phase of this doctoral study was conducted in two consecutive steps of data collection and analysis. The first step aimed to analyse the development of S-mode through studying written records accessible to the author, including official records issued by the IMO and relevant organisations, email correspondences between members of the S-mode CG, and the author's personal record. Once this step was completed, the author commenced the second step, which aimed to analyse the development of S-mode through the perspectives of the major stakeholders. The objective of this second step was to validate results of the first step and provide a more comprehensive account of the S-mode development process.

Triangulation of investigators was achieved by having multiple researchers involved in data analysis and interpretation. The author conducted data analysis independently, but the results were subsequently discussed with two supervisors. Of these two supervisors, one person was also a member of the S-mode CG while the other was not involved in the development of S-mode.

The following sections 4.3.1 and 4.3.2 will provide a detailed description of the procedures for data collection and analysis.

4.3.1. Step 1 - Document analysis

The approach in this step was inspired by the qualitative historical analysis approach, which refers to the qualitative methodological approach for studying past events by investigating documents (Thies, 2002). This approach has been employed in studying policy-making process in international negotiations, an example of which is the study on IMO Sulphur regulations for ships by Svensson (2014). As mentioned in section 1.1 on the research context, the author of this thesis was not involved with the development of the S-mode guidelines prior to 2017 and, therefore, must rely solely on historical sources for events occurred before that year.

The choice of historical documents is crucial in qualitative historical analysis. Thies (2002) categorises historical sources into primary and secondary sources. Primary sources are original materials produced on an event while secondary sources refer to documents written about an event subsequent to its occurrence. This thesis uses both primary and secondary sources in the form of:

1. Official documents including documents submitted to IMO negotiations, reports issued by various IMO organs, and supportive documents from 2007 to 2019
2. Material available to members of the group developing the S-mode guidelines, including email correspondence between members and relevant materials published by the group (reports, presentations, and magazine articles). It should be noted that the author has access to materials published during his time as a member of the group developing the S-mode guidelines (2017 – 2019)
3. Personal records of events related to the development of S-mode, kept by the author during his time as a member of the group developing the S-mode guidelines (2017-2019)

Of these three data sources, the first source generates the most amount of data as it covers the whole process of developing the S-mode guidelines since the first emergence of the concept to the final approval of the guideline. The archival procedure started with a review of documents from all NCSR sessions between 2014-2019 and NAV sessions between 2007-2013. The reason is that S-mode was an item under the agenda of e-Navigation, under the coordination of NCSR (and NAV before

2014). Any document containing information related to the concept of S-mode was shortlisted. These initial shortlisted documents led to relevant documents issued by Sub-Committee on Standards of Training and Watchkeeping [STW], MSC, as well as records of IMO events kept by delegates of member states and organisations, particularly the Norwegian Maritime Authority [NMA] (Norwegian: *Sjøfartsdirektoratet*). In total, 90 documents were included as the first data source for this study. These documents are listed in Paper IV (Vu, Lutzhoft, et al., 2022a), attached to Annex 4 of this thesis.

It is understood that each of the three data sources used in this first step has its limitations. Official IMO documents were drafted by the secretariats and, in the case of working papers, by the corresponding working groups. As a result, these documents were intentionally edited and the selection of which information to be included were not entirely objective. The same issue applies for documents drafted by IMO member states and organisations. Furthermore, there were unofficial events taking place outside of the IMO which, while not being described in official documents, had an effect on shaping the S-mode guidelines. Data from the second source – material available to members of the group developing the S-mode guidelines – are more detailed and all arguments and recommendations are recorded. However, as mentioned above, this second data source is not comprehensive as it covers the period between 2017 and 2019. The third data source contains the author's subjective interpretation of events occurred between 2017 and 2019, which means the data are incomprehensive and potentially biased. As a result, these three data sources are used in combination. The first source forms the core part of data for this phase. The second and third data sources are used to complement the first data source, providing more details on the events that occurred, adding descriptions of unofficial events not recorded in official IMO documents, and confirm the accuracy of IMO reports.

During this document analysis, the objective was to reconstruct the events during the development of the S-mode guidelines without any in-depth analysis. All gathered documents were examined in chronological order with the aim of identifying key events. As stated in section 1.4, the term "key event", as used in this thesis, refer to any occurrence that has, or might have, led to changes to either the scope of S-mode, the contents of S-mode, or the status of S-mode on the IMO agenda. Each key event was identified together with the involved actors and all relevant background information. Factors affecting each of the identified key events were categorised into technical and non-technical factors.

4.3.2. Step 2 – Interviews with major stakeholders

The results of the document analysis, as discussed in 4.3.1, provide an overview of key events during the development of S-mode and the actors involved in each event. However, this account was not comprehensive due to the weaknesses with document data as previously discussed. The next step was to address such weaknesses by collecting additional data from another source. The objectives were to provide a more comprehensive account of the development of S-mode and understand key events through the perspectives of the involving stakeholders.

To achieve the stated objectives, the author discussed results of the document analysis with major stakeholders. These discussions were conducted in the form of one-on-one interviews between the author and representatives of the identified major stakeholders.

To select the stakeholders to be studied, a stakeholder analysis was conducted using an adaptation of the stakeholder matrix version 2 of Heidrich et al. (2009). The procedure was as follows:

- The authors listed all stakeholders involved in the development of S-mode as identified in step 1
- The authors ranked the stakeholders on two characteristics: technical and political contributions. Technical contribution refers to the work performed by a stakeholder, through technical expertise and resources, to shape the contents of S-mode. Political contribution refers to the political and diplomatic work a stakeholder performed to influence IMO decisions related to S-mode

Following the stakeholder analysis, interviews were conducted with selected major stakeholders (n = 4). These interviewees represented two IMO member states: Australia and The Republic of Korea, and two NGOs: NI and CIRM.

Before the interviews, the authors shared with each interviewee a summary of the results of the document analysis in step 1, which summarised the process of developing the S-mode guidelines together identified key events. This step was done to allow the interviewees to make necessary preparations such as holding discussions within their own organisations.

The interviews were semi-structured. Using predetermined questions, the interviewees were asked to review the identified key events during the development of S-mode and give their own accounts of such events. Based on the interviewees' answers, there were follow-up questions aiming to understand such key events through the interviewees' viewpoints.

The interviews with major stakeholders generated a fourth source of data, which enriched the available data set. This fourth data source did not contradict any result obtained from the first step. Rather, the data added a level of reflection of major stakeholders on events happened during the development of S-mode and provided further explanations as to why S-mode ended up as document MSC.1/Circ.1609.

4.4. Methodological rigour

As previously mentioned, this doctoral study was conducted in two phases with different objectives and methods. The first phase, as discussed in section 4.1, involved studies conducted to design standard features on the interfaces of navigation systems following a user-centred approach. The methods and procedures for conducting these studies are detailed in Papers I, II, and III, together with discussions to justify the validity and reliability of each study.

This section only discusses the conduct of phase 2 of this doctoral study, focusing on the application of case study methodology to study the development of S-mode.

Case study is grounded in the qualitative research paradigm where the research objective is to better understand a question, problem or issue and the research questions are broadly defined. This contrasts with quantitative research which is based on precise measurements of defined variables (Denzin & Lincoln, 2018). As a result, common criteria for quantitative studies such as the use of random sampling techniques or controlled experiments are not applicable for case study research. Still, as with any other research methodology, there are established criteria to ensure case study research is conducted with rigour.

Yin (2018) suggests the following factors to consider when evaluating case study research, namely construct validity, internal validity, external validity, and reliability.

4.4.1. Construct validity

For qualitative research in general, construct validity refers to the "quality of the conceptualisation or operationalisation of the relevant concept" (Gibbert et al., 2008, p. 1466). In other words, construct validity refers to the extent to which the design and conduct of a study leads to an accurate investigation of the topic under investigation (Denzin & Lincoln, 2018).

In this doctoral study, the main research objective is to identify influential factors behind key events that shaped the development of S-mode. As previously stated in section 1.4 on research objectives, the author defines "key events" as any event or decision that led to the establishment of or changes to at least one of the following: the status of S-mode at the IMO, the scope of S-mode, or the content of S-mode. The influential factors behind each key event were identified through analysing available written records and interviews with major stakeholders.

Case study is often criticised for lacking well-considered measures and the researcher's subjective judgements are used to collect data (Meyer, 2001). To strengthen construct validity in case studies, Yin (2018) recommends three measures. One way to guard against this subjectivity is to use multiple sources of evidence and allow rival conclusions to be considered. This study responses to this suggestion by collecting data from multiple sources: official records by the IMO and other maritime organisations, email correspondence within the S-mode CG, the author's personal record, and interviews with four major stakeholders. These multiple sources of data allow the author to approach the development of S-mode from multiple angles. The interviews with major stakeholders were semi-structured and special attention was given to conflicting perspectives between interviewees. The study could have been improved by interviewing more members of the S-mode CG to generate a more comprehensive data set. However, such an attempt was not possible given the limited timeline of this doctoral study.

Another measure to strengthen construct validity is to establish a chain of evidence to allow reconstruction of the whole research process from the formation of research question to the conclusions. In this study, the author has provided a detailed description of procedures for data collection and analysis. The first data source, which contains official records from IMO and other maritime organisations, are detailed in Paper IV. Other data sources including email correspondence between members of the S-mode CG and interviews with major stakeholders are made available for a selected group of researchers.

Finally, construct validity can be improved by having the draft case study report reviewed by key informants. In response to this recommendation, the author has sent summarises of the initial findings to the interviewees for review. The same summaries were sent to two other members of the S-mode CG who were not involved in this study for review.

4.4.2. Internal validity

Internal validity refers to the causal relationships between variables and results. Having strong internal validity means the researcher has provided arguments compelling enough to defend the research conclusions (Yin, 2013).

Several measures to strengthen internal validity of case study research have been established in existing literature (Meyer, 2001; Tellis, 1997a; Yin, 2018) and can be summarised in three practical solutions: having a descriptive framework to organise the case, analyse data from both top-down and ground-up approaches, and taking due consideration to rival explanations.

The first solution requires the researcher to select or develop a structured framework to organise the case study. Such a descriptive framework can be based on the research objectives or derived from similar case studies (Yin, 2018). In this study, the author applied the concept of joint activity and organised the development of S-mode into three phases of a joint activity: the acceptance of S-mode as a part of e-Navigation, the finalisation of the scope of S-mode, and the development of the contents for S-mode.

The second solution to improve internal validity of a case study is to conduct analysis from both a top-down and a ground-up approach. By top-down, the analysis starts with theoretical propositions which, in turn, are based on the research questions or existing literature (Tellis, 1997a). In the case of this study, the basic proposition was twofold. Firstly, the author considered the development of S-mode as following the course of a joint activity which consists of several joint actions, each with separated objectives. The second theoretical preposition was that decisions at the IMO are both politically-driven and technically-driven, with politics having a stronger influence. Such theoretical proposition was based on reviewing previous studies on the way IMO develop policies and standards on the topics of nautical training and marine environmental protection, as discussed in section 2.5. The author first assumed this proposition and employed a top-down approach in analysing document data during step 1 of this study. On the other hand, a ground-up approach means employing an inductive strategy when analysing data, allowing for new patterns and insights to emerge without being limited by prepositions (Yin, 2018). The author used this strategy to analyse data collected from interviewing major stakeholders during step 2. When combining both approaches in analysing data, the author did not disregard conflicting explanations or descriptions of events that occurred during the development of S-mode. Rather, rival explanations were considered the difference in perspective between the stakeholders and were included in the findings.

4.4.3. External validity

External validity, also known as "Generalisability", refers to the extent to which a theory or explanation for a case can be valid for cases in other settings (Tellis, 1997b). The issue of generalisation is a frequent criticism of case study since context plays an integral part in a case and, as a results, findings in case studies are context-dependent. Also, case studies often do not study a sample of cases significant enough to allow for statistical generalisation, such as to infer conclusions about a population (Numagami, 1998). Yin (2013) counters this criticism and points out that it is not statistical generalisation but rather analytical generalisation that forms the basis of case studies.

In statistical generalisation, an inference about a population is built upon the basis of data collected from a sample of said population. In analytical generalisation, an inference is made about a theory based on results from examining a specific case or specific cases. In this way, the generalisation is made to theory and not to population and refers to the extent to which such theory can be used to explain similar phenomenon in similar scenarios (Maxwell, 1992).

A measure to increase the generalisability is to apply a multi-case approach which allows for cross-case comparison. Eisenhardt (1989) suggests a cross-case analysis with four to ten cases can serve as a strong basis for theory development. This recommendation, however, is not applicable for this doctoral study due to the limited time frame of the research project as well as the resource available to the author of this thesis. However, the author did employ an alternative measure to improve generalisability by comparing the case of S-mode with two related studies: the study on marine environmental protection regulations by Svensson (2014) and the study on training standards for seafarers by Dirks (2004), both of which are discussed in section 2.5. This measure is comparable to the conduct of different case studies within one organisation, which is the IMO in this case, as suggested by Yin (2018).

4.4.4. Reliability

Reliability refers to the absence of random error during the conduct of a research. Reliability is expressed by the degree to which a study can be replicated by other researchers following the same procedures and still yield the same results (Denzin & Lincoln, 2018).

The key considerations for reliability in case study are "transparency" and "replication" (Gibbert et al., 2008, p. 1468). Transparency can be achieved by clarifying in detail the research procedure, such as by producing a case study protocol. Replication can be achieved by making available a case study database which should include research materials such as documents, notes, records, etc. Such a database should be organised in such a way to facilitate retrieval for other researchers or evaluators (Yin, 2018).

In this study, the author has provided a detailed description of all activities associated with the conduct of this case study on the development of S-mode. As mentioned in section 4.4.1 on construct validity, all data used in this study have been made available for a group of researchers. The questionnaires used to conduct interviews with stakeholders are also made available in Paper IV. This arrangement allows easy replication of this study by other researchers.

In summary, the author has discussed in this chapter the overall design of this doctoral study, the choice of methodologies, and procedures for conducting each research phase. The following chapters 5, 6, and 7 discuss the findings and contributions of this study. Considering the importance of these three chapters and for the convenience of readers, the author once again summarises the contents of chapters 5, 6, and 7 as follow:

- Chapter 5 outlines the development of S-mode from the emergence of the S-mode concept in 2007 to the finalisation of the scope for S-mode guidelines in NCSR 5. The chapter focuses on two aspects: the status of S-mode as an official part of e-Navigation and the negotiations taken to reach a scope of S-mode agreeable to majority of the stakeholders
- Chapter 6 details the work taken to develop the four standard features forming the core of the S-mode guidelines. This chapter focuses on the technical aspect of the development work, viewing it as a user-centred design project. In other words, this chapter presents results of the usability studies forming phase 1 of this doctoral study, as discussed in section 4.1
- Chapter 7 analyses key events during the development of S-mode, identifying factors affecting each event. The chapter then suggests factors should be considered for future initiative similar to S-mode. In other words, this chapter presents results of the case study on S-mode forming phase 2 of this doctoral study, as discussed in section 4.2

5. The evolution of S-mode

This chapter describes the evolution of S-mode from a concept suggested by maritime professionals to an official IMO project. The chapter focuses on two aspects in the development of the S-mode guidelines: the achievement of official status as a part of e-Navigation and the finalisation of the scope.

5.1. The origin of the S-mode concept

Toward the late 1990s, the NI started observing an increased level of sophistication and complexity with navigation systems, particularly with the Radar. The Institute also, at the time, had a vision that the future of bridge equipment would be integrated navigation systems. Considering potential issues with future navigation equipment, the NI held a series of international conferences on Integrated Bridge Systems and Human Element in 2002 and 2003. The attendees represented several industry stakeholders including equipment manufacturers, seafarers, and researchers. Many interesting topics were discussed but there was one particular discussion where delegates raised concern that navigation equipment was getting too diverse in terms of user interfaces and functionalities. Delegates were also concerned that the training were focusing mainly on teaching seafarers to use different functions and controls rather than teaching them how to use the equipment to navigate safely and effectively. The delegates argued that a greater level of equipment standardisation was needed, which would facilitate training and familiarisation. The NI subsequently submitted a paper to the IMO summarising the issues raised during the conferences. The IMO acknowledged these issues in circular MSC/Circ.1091 (IMO, 2003), which serves as the official recommendations for member states to consider when introducing new technology on board.

When the concept of e-Navigation emerged in 2005, one part of the concept involved improving the standardisation of bridge equipment (IMO, 2005). The NI recalled document MSC/Circ.1091 and started to work on finding a solution for this standardisation issue, in close collaboration with manufacturers of marine electronics through the CIRM. The manufacturers did not unreservedly support further standardisation efforts, believing that an increased level of standardisation would limit the ability to innovate and introduce new features. Such a limitation could force innovative manufacturers to cut back on their research and development [R&D] to be able to compete with manufacturers who produce low-cost systems with basic functionalities. The NI recognised the merit of this argument and came up with a solution: a separate standard interface, called “S-mode”, would exist alongside the brand-specific interface developed by each manufacturer. The NI believed that such a stand-alone standard interface would bring improved standardisation while still leaving room for manufacturers to innovate.

The idea received supporting feedback from maritime professionals (Patraiko, 2007) so the NI, together with the IFSMA, introduced this “S-mode” concept to the e-Navigation Correspondence Group (hereby abbreviated as “**the e-Nav CG**”) during NAV 53 in 2007. This introduction took into account the aligned goals of both S-mode and e-Navigation, suggesting that S-mode could potentially support the objective of e-Navigation in improving navigation decision making and, therefore, could be a part of the e-Navigation initiative. This was the first time S-mode was mentioned at NAV. The e-Nav CG, that time chaired by the United Kingdom, expressed interest in S-mode but ultimately concluded that the concept was premature at the time and declined endorsement. However, the e-Nav CG welcomed the initiative and invited the IFSMA to update the group of future progress (IMO, 2007d).

The S-mode concept was negatively received by marine electronic companies. While many complex arguments were made against S-mode, one persistent motivation from manufacturers was that they wanted the freedom in designing their products to use innovative features as selling points. Considering the large number of manufacturers (as of October 2021, there were 106[6] members of CIRM) in such a small market as marine electronics, innovation and unique selling points are important to secure market share. Additionally, a standard interface could potentially lock in users, making it difficult for any subsequent change/update. On the other hand, there were arguments supporting S-mode, referring to published studies and particularly document MSC/Circ.1091, which recognised the lack of standardisation in equipment design as a real issue (IMO, 2003). Furthermore, there were recommendations from COMSAR during their 11th session calling for the standardisation of interfaces and operating modes for navigation equipment (IMO, 2007a). However, the discussions were inconclusive, and the development of S-mode was left for the NI and IFSMA to continue.

The following year (2008), NI and IFSMA worked to expand the S-mode concept and submitted an information document to NAV 54 (IMO, 2008b). This document retained the original S-mode concept as a standardised display mode for navigation systems that can be quickly activated. The document also provided more details of how S-mode could be implemented in practice and described a general plan for development, which involved studying user needs and testing prototypes. NAV acknowledged this development but provided no further comments. The main focus of NAV, at the time, was to formulate a detailed e-Navigation concept in the form of a strategy implementation plan [e-Nav SIP] (IMO, 2008c) and S-mode was not a priority. As a result, the development of S-mode in subsequent years were uncoordinated and undertaken voluntarily by interested parties, including the NI, IFSMA, and researchers from academia.

[6] It should be noted that although not all 106 CIRM members are manufacturers of marine electronics, a majority of them are. There are also government agencies such as the UK Hydrographic Office or the US Coast Guard among the members.

5.2. Becoming a part of e-Navigation

From 2008 until the adoption of the e-Nav SIP in 2014, there was limited development of S-mode. The main development of S-mode during this period focused on getting S-mode accepted as part of the e-Navigation initiative. To this end, several studies were conducted to demonstrate the potential benefits S-mode could bring to e-Navigation. The first study was the one conducted by the IFSMA in collaboration with the NI from 2006 to 2009. The study aimed to identify what seafarers need from future technology. The results were reported to NAV 55 by the IFSMA in the form of an information paper. The study employed several methods including ship visits, interviews, technical meetings with seafarers, discussions among correspondence groups, networking, and discussions in technical journals. The findings suggested that seafarers needed a means to standardise the location and presentation of certain information, system menus, and interface devices such as knobs or joysticks on navigation displays, to which S-mode could be an solution (IMO, 2009b).

Many IMO member states showed interest in the S-mode concept and started considering the potential benefits of S-mode for the e-Navigation initiative. Germany and Canada jointly developed a questionnaire to study user needs for e-Navigation and each country launched the survey independently. Germany launched the survey worldwide and collected data from 353 participants. The results, which were submitted as an information paper to NAV 55 (IMO, 2009a) showed that most participants supported the S-mode concept, commenting that a standardised mode of operation would be beneficial for pilots and seafarers who frequently change ships or company. Survey respondents also suggested that S-mode should be continuously revised to stay updated as technology advances. Canada launched their survey from May to October 2009 and specifically targeted Canadian maritime professionals (n = 177). The results were submitted to NAV 56 in 2010 and indicate that that most participants were in favour of the S-mode concept but there was little consensus on the content of S-mode and how the concept should be developed. The main supporting arguments were that S-mode could facilitate familiarisation with new equipment when joining new ships as well as providing seafarers with technology solutions that would be more user-friendly (IMO, 2010a). Also, during NAV 56, the Republic of Korea (hereafter referred to as "ROK") submitted a summary of a discussion on gap analysis of e-Navigation done by members of a Korean expert's forum on e-Navigation issues. The discussion did not expand on the initial concept of S-mode, but listed potential benefits of implementing S-mode, thus expressing favour for S-mode to be a part of e-Navigation. The main argument supporting S-mode was that such a concept would improve the usability of navigation system, allow seafarers easy access to essential information needed for conducting different navigation tasks (IMO, 2010b).

Later in 2010, the e-Nav CG submitted a report of their work in NAV 56 to the STW and requested the Sub-committee to consider the potential impact of S-mode on seafarer competency (IMO, 2010c). In response, the STW, during their 42nd session in early 2011, commented with support of the development of S-mode. It was the STW's view that S-mode would support the familiarisation process and enhance safety of navigation. Italy suggested focusing S-mode on Integrated Bridge Systems (IBS), conducting usability tests on prototypes and taking into account the transfer of data between navigation and engine automation (IMO, 2011).

All the aforementioned results were considered when the e-Nav CG conducted the gap analysis to develop the e-Nav SIP. The intention of this analysis was to identify the gap between current technology and the identified user needs and, subsequently, what should be included in e-Navigation to address such gaps. Results of this analysis pointed toward a need for the application of good ergonomic principles in well-structured human machine interfaces as a part of e-Navigation (IMO, 2012a). Based on these results, the e-Nav CG suggested incorporating S-mode into the agenda of e-Navigation, under the sub-solution number S1.4 (IMO, 2012b).

A critical moment in the development of S-mode took place in NCSR 1 in 2014 when the e-Nav SIP was expected to be finalised. The CIRM submitted a proposal to remove S-mode from the e-Nav SIP, pointing out several issues with the concept (IMO, 2014b). Firstly, the implementation of S-mode, as the concept was currently described, would remove the incentive for manufacturers to produce their own interfaces as there would be no need for type-specific training and seafarers would have little interest in using manufacturer-customised interfaces instead of S-mode. Secondly, S-mode could make it difficult for manufacturers to update their systems to keep up with technological advancement or in case user requirements changed. Additionally, S-mode would make it difficult to cater to specific needs of different markets or maritime sectors. Finally, there had already been other initiatives that could also bring improved usability to navigation systems without the need for a fully standardised interface. Specifically, the introduction of standard default settings, the function to save/recall user settings, suggested logical grouping of contents, the use of standardised icons, standard terminologies and abbreviations. As a result, CIRM expressed concern that S-mode would overlap with existing initiatives, introduce new challenges, and delay the implementation of e-Navigation.

CIRM's proposal received support from many delegates, specifically:

- International Maritime Pilots' Association [IMPA] – maritime pilots had given the topic of S-mode deep consideration based on experience of using different equipment and modes and supported CIRM's proposal. The IMPA believed that alternative solutions such as the introduction of save/recall functionalities would be more pragmatic and bring real benefits

- The US commented that they did not believe S-mode to be a suitable e-Navigation solution but, at the same time, did not disregard S-mode completely

- Sweden, Japan, the Netherland, and France also supported CIRM's proposal

However, there were strong opinions for S-mode and against CIRM's proposal, specifically:

- Australia agreed with some of CIRM's arguments but believed that there was insufficient evidence to evaluate how much alternative measures could address the issues with lack of equipment standardisation. Until it could be proven otherwise, Australia supported retaining S-mode in the e-Navigation SIP

- Denmark supported the S-mode concept, believing that it would address user needs, and did not believe that S-mode would impact manufacturers' ability to innovate. Denmark commented that the industry had reached a level of diversity where a solution like S-mode would be necessary

- Norway supported Denmark's comment and also voted to retain S-mode in the SIP. Norway further commented that S-mode received a lot of support from delegates during the 42^{nd} session of IMO sub-committee on standards of training and watchkeeping [STW] and, therefore, believed that there was a need for a concept like S-mode

- The International Association of Independent Tanker Owners [INTERTANKO] believed S-mode to be critical for safety and, therefore, did not support removing S-mode from the e-Navigation SIP

- The NI argued that S-mode would address user needs as currently users had to adapt to various systems made by different manufacturers. The NI also stated that studies by IMO member states had found S-mode to be a suitable e-Navigation solution and they did not consider alternative measures mentioned in CIRM's proposal to be adequate for addressing the identified user needs

- Singapore, the Bahamas, the Marshall Islands, Panama, Kiribati, the Republic of Korea, Nigeria, and Poland supported retaining S-mode in the e-Navigation agenda, citing the arguments of Norway, Denmark, NI and INTERTANKO

Concluding NCSR 1, CIRM's proposal was not approved, and S-mode remained a part of the e-Navigation SIP. The strong support from a large number of IMO member states assured S-mode a firm position as an e-Navigation solution. The status of S-mode as an e-Navigation solution was officialised after the MSC approved the e-Navigation SIP in November 2014 (IMO, 2014a).

5.3. Defining a scope

Following the adoption of S-mode as a part of e-Navigation in NCSR 1, the MSC set out a plan to develop S-mode with a goal to complete the work in 2019 (IMO, 2015a, 2015b). Since the number of correspondence groups had reached the limit, an informal correspondence group on S-mode was formed under the coordination of Australia in 2015. The S-mode correspondence group, hereby abbreviated as "the S-mode CG", worked on two tasks simultaneously: organising workshops and discussions to agree on a scope of S-mode and conducting user studies to identify user needs regarding the standardisation of navigation equipment. This section discusses the work performed to reach agreement on a scope of S-mode while details of the user studies are provided in section 6.1.

Starting from 2015, members of the informal S-mode correspondence group held several meetings and discussions to work out details of a S-mode concept that could be acceptable to all parties involved. An important workshop was held in South Korea in 2015, in which the International Electrotechnical Commission [IEC] and CIRM proposed that S-mode should not be a fully-standardised separate display mode but rather the standardisation of certain features of the interfaces such as indicators, presentation of essential information, and common terminologies (IMO, 2015e). This proposal was not adopted as the official S-mode agenda but involving parties agreed that a fully standardised interface would no longer be prioritised, should other solutions be able to bring similar usability benefits (IMO, 2016). This 2015 workshop also marked the time when the CIRM started participating more actively in the development of S-mode to ensure their inputs would be reflected in the final outcome as it would be the manufacturers who must subsequently implement S-mode.

Further discussions during 2015-2016 saw S-mode gradually depart from the initial concept of fully-standardised interface mode(s) for navigation systems. As of 2016, it was envisioned that S-mode would become a set of standard guidelines for designing navigation equipment, which would also standardise certain features of the interfaces (IMO, 2016). Still, the S-mode correspondence group could not agree on the exact scope of S-mode, including questions such as to which equipment S-mode would be applied, which features of the interfaces would be standardised, and how such standard features would be developed. Nevertheless, the groups agreed that the overall goal of S-mode would be to reduce the necessary training efforts and improve usability of navigation equipment.

The CIRM had several concerns with S-mode at the stage of 2016. They felt that some members of the S-mode correspondence group were aiming for S-mode to be overly prescriptive standards. The CIRM reaffirmed their stand that they would not support a rigid and comprehensive standardisation and urged other members to aim for a "middle ground". The CIRM also believed that S-mode, in the current form, was too abstract and could not be implemented. Another issue was that S-mode was intended to be an IMO guideline, which is the weakest IMO regulatory instrument and would not give manufacturers a regulatory incentive for implementation. Considering these factors, the CIRM formed their own S-mode Working Group to develop an alternative S-mode solution. It should be noted that this S-mode Working Group is an organ within the CIRM and, despite being called a Working Group, has nothing in common with Working Groups formed at each IMO session. They presented their results during the e-Navigation underway Asia-Pacific 2017 conference in South Korea.

This alternative S-mode concept, as proposed by CIRM, would not standardise the whole graphical user interfaces of various navigation equipment but, instead, would standardise four features of the interfaces:

- Icons and terminologies for key functions and concepts
- The grouping of key functions and controls
- Quickly accessible functions, which must be accessible by either single or simple operator actions

- Default system settings for Radar and ECDIS

These four standard features could be applied to a wide range of bridge equipment. In their proposal, the CIRM introduced an initial version of the four standard features, developed by CIRM's own S-mode Working Group.

CIRM's alternative S-mode quickly gained support from most members of the S-mode correspondence group as this was, by far, the only solution with sufficient clarity and a clear development pathway. The initial edition of the standard interface features, as proposed by the CIRM, gave a clear vision of what the final outcome of S-mode would be like, and the logical next step would be conducting usability tests to evaluate these initial designs and modify as necessary. Also, the goal of S-mode was never to introduce a fully standardised interface but rather to find a solution to improve the standardisation of bridge equipment, which this alternative S-mode concept did support. The specific opinions of each involving stakeholder, as recorded in email correspondences between members of the S-mode correspondence group, were as below:

- Germany supported CIRM's proposal but also commented that more work needed to finalise the standard interface features

- Japan supported the CIRM's proposal but also suggested additional functions of navigation system to be added to S-mode as well as changes to some of the proposed icons

- NI supported the CIRM's proposal, stating that, based on comments from seagoing members, this new S-mode concept has the possibility of meeting the original goals of the S-mode concept without requiring the introduction of a stand-alone standard interface mode. The NI suggested that the interface features, as proposed by the CIRM, should be tested with seafarers worldwide and agreed to work with like-minded members of the S-mode CG to develop S-mode following this new approach

- An observer from Dalian Maritime University supported NI's suggestion for testing of the proposed interface features

- An observer from Lloyd's Register supported CIRM's proposal and suggested testing of the proposed interface features. The observer also suggested ensuring compliance with ergonomics standards and alignment with existing bridge equipment standards

- American Pilots' Association supported CIRM's proposal

- BIMCO supported CIRM's proposal and suggested a few modifications to the proposed interface features

With the support from the majority of members of the S-mode CG, CIRM's proposal was included in the group's submission to NCSR 5 (IMO, 2017a) and was subsequently incorporated into to the official scope of S-mode, approved in NCSR 5 (IMO, 2018a).

The finalised scope of S-mode, as set out in document NCSR 5/7 (IMO, 2017a), contained a set of human factors guidelines applicable for the design navigation systems and four standard features of navigation displays as proposed by the CIRM. It was expected that S-mode would become official as an IMO circular. The NCSR also officialised the informal S-mode CG as an official correspondence group, still under the coordination of Australia, and instructed the S-mode CG to complete the development of S-mode. Since the scope of S-mode had been determined, the main work of the S-mode correspondence group during 2018-2019 was to develop and finalise contents of the S-mode guidelines, focusing on the standard features. Chapter 6 provides details of the work performed to evaluate and finalise the contents of the S-mode guidelines.

6. Developing contents for the S-mode guidelines

Following the adoption of S-mode as a part of e-Navigation in NCSR 1, the MSC set out a plan to develop S-mode with the expected completion year of 2019 (IMO, 2015a, 2015b).

The development of contents for the S-mode guidelines could be categorised into two periods, before and after the finalisation of the scope of S-mode in NCSR 5. Before NCSR 5, most of the development work focused on studying user needs for S-mode, the purpose of which was to provide inputs to make decisions regarding the scope of S-mode. The work after NCSR 5 focused on evaluating and modifying the standard design features as proposed by CIRM in NCSR 5.

The four features of the interfaces for navigation systems to be standardised by S-mode were developed following a user-centred approach, the purpose of which is to ensure these features would result in interfaces with high usability to aid seafarers in their navigation tasks. The development process included activities of a UCD process as prescribed in standard ISO 9241:2010 (ISO, 2010). In specific, the development of S-mode involved studying the context in which navigation tasks are conducted onboard ships, identifying what seafarers required from bridge equipment to perform such navigation tasks, and develop standard designs for equipment interfaces to accommodate users' requirements. Details of these activities are discussed in the following sections.

6.1. Understanding the context of use and user requirements

Before the finalisation of the scope of S-mode in NCSR 5, it was not possible to determine what the content of S-mode would be. As a result, the development work during that time focused mainly on understanding the context in which seafarers operate navigation equipment and identify what seafarers require from navigation equipment to do their jobs. Before the formation of an informal S-mode CG in 2015, as discussed in section 5.3, the development of S-mode was uncoordinated and undertaken voluntarily by parties interested in S-mode, including both organisations and independent researchers.

The earliest published study on S-mode was done by Jacobson and Lutzhoft (2008) from Chalmers University of Technology with the participation of 54 seafarers of the Swedish naval and merchant fleets, aiming to identify user-preferred default presentation settings for Radar equipment. Another study with a similar goal of identifying user preferred settings and interface layouts focusing on ECDIS Route Monitoring displays was conducted by Lutzhoft et al. (2016) with data collected from 50 maritime professionals.

The aforementioned studies were considered when developing S-mode. However, the main data on context of use and use requirements for developing S-mode were results of the research conducted by two members of the S-mode CG: the NI and ROK. The author of this thesis was responsible for conducting usability studies on behalf of the NI, while the Korea Research Institute of Ship & Ocean Engineering [KRISO] and Korea Maritime & Ocean University [KMOU] conducted studies on behalf of the ROK (IMO, 2017b). These studies are discussed in the following sections 6.1.1 and 6.1.2.

6.1.1. Studies conducted by the NI

On behalf of the NI, the author of this thesis conducted three studies to establish an overview of the way seafarers operate navigation equipment under various scenarios. The methods of these studies were discussed in section 4.1. The following paragraphs only provide a summary of these studies.

The first study was a review of cognitive analyses of marine navigation tasks. The aim of this study was to identify which tasks a mariner perform when engaging in navigation duties, and which functions of bridge equipment are required to support each task. In this study, the author did not conduct a new analysis of marine navigation tasks but reviewed existing analyses, identified the merits and weaknesses of each analysis, and combined them into a single analysis. The selected analyses were done by Sanquist et al. (1994), Røed (2007), Procee et al. (2017), Van Westrenen (1999), and Koester et al. (2007). Results of this study took the form of a technical report distributed to members of the S-mode CG and was not published as an independent academic publication. A copy of said report is attached to Annex 5 of this thesis.

The second study involved reviewing performance standards for marine navigation systems to identify mandatory functions. Performance standards for Radar (IMO, 2004), ECDIS (IMO, 2006b), and INS (IMO, 2007b) were considered. This approach was chosen to account for the variety in design and functionality of systems between different manufacturers. Results of this study also took the form of a technical report distributed to members of the S-mode CG and was not published as an independent academic publication. These results are also attached to Annex 6 of the thesis.

The third activity involved a survey on the frequency of which seafarers use each function of a standard INS when performing navigation duties. The survey also collected data on the purpose of each function and scenarios in which the functions are utilised, with results collected from 601 seafarers worldwide. Details of the survey and the results are published in Paper I (Vu et al., 2019), attached to Annex 1 of this thesis.

6.1.2. Studies performed by the ROK

Starting in 2017, the ROK developed an online platform to collect input from seafarers. It was the ROK's view that standardising the vast array of functions and contents on navigation displays would be ill-advised as it would be difficult to get user input, and such a wide level of standardisation would impede innovation from manufacturers. Instead, the ROK envisioned that S-mode would focused on a standard ECDIS screen with standardised top-level menu items. From October to November 2017, the ROK launched their online data collection platform. Participants (n = 333), who were maritime professionals, provided inputs on user-selected contents of ECDIS main displays and head menus as well as the arrangement of contents on the main display and menus. Results of this work was submitted as an information paper to NCSR 5 (IMO, 2017b).

In 2018, the ROK conducted two studies to collect additional data on the way seafarers operate navigation equipment. The researchers first reviewed international standards and guidelines for watch-keeping including STCW, the Bridge Procedure Guide from the International Chamber of Shipping [ICS], and the NI familiarisation checklist for ECDIS to identify 22 tasks essential for safe navigation. These 22 tasks are performed on both Radar and ECDIS and their equivalent modules on an INS and serve three purposes: voyage planning, route monitoring, and avoiding collision. These tasks are listed in Annex 1 of document NCSR 6/INF.13 (IMO, 2018c). The second study involves using eye-tracking devices to identify information on ECDIS and Radar that is of interest to seafarers when engaging in watch-keeping duties. Three navigators wore eye-tracking devices when conducting the navigation of a Ro-Ro vessel between Busan and Osaka. A similar experiment was recreated in a bridge simulator with the participant of two other navigators. Data from both experiments were analysed and helped identify information on Radar and ECDIS displays that is essential for safe navigation Results of this study are reported in Annex 3 of document NCSR 6/INF.13 (IMO, 2018c).

In combination, the two studies conducted by the NI and the ROK formed the basis of understanding on the way seafarers operate navigation equipment when engaging in navigation duties. From there, the results confirmed that the interface features to be standardised by S-mode, as detailed in document NCSR 5/7 (IMO, 2017a), had covered most functions of navigation equipment that were essential to support safe navigation. An exception was the function to change between true and relative vector mode, which would subsequently be added to the S-mode guidelines.

The following sections describe the usability studies conducted in 2018 and 2019 and the considerations taken to evaluate, modify, and finalise the four standard interface features forming the core of the S-mode guidelines.

6.2. Initial design solutions

The first edition of the four features on the interfaces of navigation systems forming the core content of the S-mode guidelines was developed by the CIRM's S-mode Working Group and first introduced to the S-mode CG following the e-Navigation underway Asia-Pacific 2017 conference. These first edition standard features are detailed in Appendixes 2, 3, 4, and 5 of document NCSR 5/7 (IMO, 2017a).

At this point, all four features, including the icons and terminologies, the grouping of key controls, the list of quickly accessible functions, and the sets of default system configurations for Radar and ECDIS, were only preliminary. Parts of these standard features were directly derived from existing performance standards while other parts introduced new requirements. The CIRM developed these new requirements based on their experience, which drawn from varied backgrounds including equipment manufacturers, service organisations, training organisations, and seafarers as end-users of navigation equipment.

It should be noted that the CIRM finished developing this first edition of the standard features while researchers from the NI and ROK were still conducting studies on context of use and user requirements as described in section 6.1.1 and 6.1.2. In a typical user-centred design process, the step of developing design solutions is often carried out after the context of use and user requirements has been studied thoroughly. In the case of S-mode, the work was undertaken by various organisations independent of each other and the coordination between such organisations was, as a result, not as cohesive as in the case of a work undertaken by a single organisation. Nevertheless, results from the studies described in sections 6.1.1 and 6.1.2 were considered when evaluating this first edition of the standard features.

The following step in the development of S-mode was to evaluate the four standard features to see if they satisfy the requirements of seafarers and carry out modifications if necessary. The S-mode CG agreed that this step would involve conducting usability tests with the participant of seafarers. Besides the goal of usability, the group also aimed to maintain alignment with existing ergonomics standards and performance standards for bridge equipment. Chapter 6.3 provides details of the work taken to evaluate and finalise the four standard interface features, which form the core of the S-mode guidelines.

6.3. Standard features on the interface of navigation systems

As discussed in section 5.3, the finalised scope of S-mode was accepted in NCSR 5 and contained general design guidelines together with four standard features of the interfaces of navigation systems. These four features are: icons and terminologies, the grouping of essential controls, the list of functions that must be accessible by single or simple operator actions, and default system settings for ECDIS and Radar. The first edition of these four standard features were developed by CIRM and incorporated into document NCSR5/7 (IMO, 2017a). Following NCSR 5, the task of the S-mode CG was to conduct usability tests to evaluate the four standard features and carried out necessary modifications. The following sections provide details of these usability tests.

6.3.1. Standard icons and terminologies

The first edition of the standard navigation-related terminologies and standard icons to be used on navigation systems was developed by CIRM and listed in Appendix 1 of document NCSR 5/7. The majority of the icons and terminologies introduced in this edition strictly followed existing standards, particularly performance standards for shipborne radar (IEC, 2007) and performance standards for the presentation of navigation-related information on shipborne navigational displays (IEC, 2014; IMO, 2014c), although the CIRM did introduce new icons and terminologies for nautical concepts not already covered in existing standards. In total, 59 icons and their associated labels/terminologies were included in document NCSR 5/7

Members of the S-mode CG conducted usability tests on these icons and terminologies. Results of the tests together with recommendations were subsequently submitted to the S-mode CG for consideration. The S-mode CG discussed the results and collectively made decisions on follow-up actions. The author of this thesis designed and conducted two usability studies to evaluate these first-edition standard icons and terminologies.

The first study involved face-to-face interviews with master mariners (n = 5), three of whom were from India and two from Denmark. The interviews were conducted on January 23, 2018, at the headquarter of the Baltic and International Maritime Council [BIMCO] in Copenhagen. In the interviews, the 59 icons were shown to each participant one by one, the first time without the associated labels and the second time with the labels. For each icon, the participant was provided basic context such as the equipment or the type of functionality and asked to interpret its meaning. The interviewer asked follow- up questions to explore the reasoning behind the interpretation. The participants were encouraged to provide additional comments regarding the design of the icons in question and to suggest alternative icon designs if desired.

The second study involved an online survey which followed a reverse approach to the interviews in the first study. Instead of showing an icon, each survey question would show participants a function of bridge equipment and ask them to select, among three available options, the one most suitable for conveying the intended message. Regardless of the answer, the survey would then reveal the meanings of all three icons, and participants could provide additional comments. The survey was performed online from February to April 2018 and contained 59 questions, each addressing one of the 59 icons. The number of respondents differed between questions, ranging from 27 to 45.

Results of these two studies were combined to provide a more comprehensive evaluation of the usability of the 59 icons and their associated labels. The findings suggested some of the icons were difficult for seafarers to comprehend and should be modified. Interestingly, some of the standard icons already prescribed in existing performance standards were found among the poorly comprehensible icons. These icons are discussed in an article by Vu and Lutzhoft (2019). Annex 7 of this thesis contains the full results of these usability studies.

As discussed in section 6.1, researchers from ROK conducted studies to identify which functions from bride equipment are essential for safe navigation and most of these functions were covered in the first edition of the S-mode guidelines, as detailed in document NCSR 5/7 (IMO, 2017a). An exception was the lack of an icon for the function to select true and relative vector mode. As a result, the ROK suggested adding an icon for the function to select vector mode, which was incorporated to Annex 3 of document NCSR 6/7. They also suggested changes to icons for functions to increase and decrease display range scale (IMO, 2018b).

Results of the aforementioned studies were submitted to the S-mode CG for consideration. During the period from May to October 2018, members of the S-mode CG discussed potential changes to some of the icons. Main contributors for the work during this time were Australia, Japan, the ROK, Poland, Germany, Norway, the NI, CIRM, and the IEC. Besides the studies mentioned above, no other formal usability test was conducted and there was no other large-scale involvement of seafarers. All considerations and decisions were made by members of the S-mode CG, who represented a large variety of stakeholders including equipment manufacturers, human factors specialists, and master mariners. Members of the S-mode CG communicated via emails and comments/discussions were made in five rounds. As the coordinator, Australia collected and compiled inputs from members the group after each round. As a result, it took time for the members to reach an agreement.

Given the deadline of October 2018 to submit a report to NCSR 6, the S-mode CG had to adopt a pragmatic working principle. If a solution, such as a modification to an icon or a suggestion of a new label or term for a concept, immediately received mainstream support from the majority of members, it would be adopted. If a solution lacked immediate mainstream support and required a lot of discussion or additional development, the correspondence group would remove it from S-mode. While this practice ensured the delivery of S-mode by the deadline of October 2018, it also meant that results from usability studies were not fully incorporated into the final edition of S-mode. Specifically in the case of standard icons, all icons for Radar control functions were subsequently removed from S-mode. Also, it was not possible to find suitable pictographs to convey certain concepts and the group decided to use text labels instead of pictographs for such concepts. The finalised icons, listed in Appendix 2 of document NCSR 6/7, were submitted to NCSR 6 for consideration. Discussions in NCSR 6 did not lead to any change and the finalised icons were approved as official in Appendix 2 of the S-mode guidelines (IMO, 2019b).

6.3.2. Logical grouping of essential information

Similar to the standard icons discussed in 6.2.1, researchers from the CIRM who developed the first edition of the second standard feature - a pattern to organise essential information on navigational displays into groups. This pattern followed existing standards including IEC 62288:2014 and MSC.191(79). However, this first edition, as prescribed in Appendix 2 of document NCSR 5/7 (IMO, 2017a), was very limited in scope.

To evaluate and expand the scope of this feature, the author of this thesis conducted a study to develop a pattern to group essential contents on the displays of Radar and ECDIS or the equivalent modules on an INS. Based on results of the studies on context of use and user requirements discussed in 6.1.1, the author identified functions of

Radar and ECDIS most essential for safe navigation and should be readily available on the displays. To develop a logical pattern to organise these essential functions into groups, the author used a method called “card sorting”. In specific, the study employed the following procedure:

- From the identified essential Radar and ECDIS functions, 49 functions were selected to be included in this study. These 49 functions were selected after several pilot studies to achieve the most completeness of data while also preventing the research subjects from being fatigued
- The author prepared a set of 49 cards, each with the name of one of the 49 selected Radar and ECDIS functions
- The author presented the cards to the research participants, who were also seafarers. Participants were asked to sort the cards into groups in any way that made sense to them

Grouping patterns created by the research subjects (n = 63) were merged using a statistical classification technique called Advanced Merge Method (AMM), to create a single grouping pattern. Compared to the pattern proposed by the CIRM in document NCSR 5/7, there was no conflict and the two grouping patterns could be combined. Full details of this study are contained in a paper presented at Human Factors 2018 Conference in London, United Kingdom (Vu & Lutzhoft, 2018).

The grouping pattern resulted from this study was submitted to the S-mode CG for consideration. It should be noted that this grouping pattern could not be considered scientifically final due to several methodological weaknesses of the card sorting method that must be addressed. In particular:

- In card-sorting experiments, participants put content into groups (classifying). In actual usage scenarios, people look for information. There are differences between classifying and finding content (Spencer, 2009)

- Unless participants think out loud while sorting the cards, card-sorting cannot capture the rationale behind the grouping patterns (Maiden & Hare, 1998)

- Card-sorting does not produce concretely defined categories. It is very unlikely that research participants agree on everything and there will be disagreement at different extends in many cases. As a result, there is certain degree of intuition involved in the data analysis process (Brucker, 2010)

Considering these issues, the author recommended the S-mode CG to conduct another study to validate the submitted grouping pattern, hereby referred to as the "initial grouping pattern". However, this validation study was not conducted in time to meet the deadline of October 2018. After several discussions, the S-mode CG decided to adopt minor changes to the original grouping pattern suggested by the CIRM and reported the new grouping pattern in Annex 3 of document NCSR 6/7 (IMO, 2018b). This grouping pattern was subsequently approved in MSC 101 to be an official standard. Similar to the standard icons discussed in section 6.2.1, in the case of the grouping pattern, results of usability studies were not fully incorporated due to time constraints.

Nevertheless, the author did conduct another study to validate the initial grouping pattern, although this study occurred after the approval of the S-mode guidelines in 2019. This study involves testing the initial grouping pattern with seafarers of various ranks and nationalities (n = 35) to evaluate the degree to which the initial grouping pattern fits the perceptions of users. The results suggest that the initial grouping pattern, as well as the pattern incorporated in Appendix 3 of the S-mode guidelines (IMO, 2019b), matches the typical perception of seafarers. This finding gives confidence that organising information on navigational displays following the grouping pattern introduced in S-mode can lead to improved usability. Full details of the methods and results of this study are presented in Paper III, which has been accepted for publication at Journal of Navigation (Vu, Lützhöft, et al., 2022). The paper is attached to Annex 3 of this thesis.

6.3.3. Functions that must be accessible by single or simple operator actions

The third feature on the interfaces of navigation systems to be standardised by the S-mode guidelines is the list of quickly accessible functions. All functions on this list must be accessible by either single or simple operator action.

Similar to the first two standard features discussed in 6.2.1 and 6.2.2, the original list of functions that must be accessible by single or simple operator actions were developed by the CIRM and included in Appendix 3 of document NCSR 5/7 (IMO, 2017a). The terms “single operator action” and “simple operator action” were directly taken from performance standards for INS – resolution MSC.252(83) (IMO, 2007b). A single operator action means a procedure requiring only a single hard-key or soft-key press while a simple operator action means a procedure requiring no more than two hard-key or soft-key actions, excluding any cursor movements or voice commands.

The first edition of this list, as presented in NCSR 5/7, contains two parts. The first part includes functions already prescribed in existing standards, specifically IEC 62388:2012, IEC 62288:2014, and IEC 61174:2015. This first part is required to ensure alignment with existing bridge equipment standards. The second part of the list contains functions not prescribed in any standard at the time.

The NI hosted a survey to collect inputs from seafarers regarding functions that must be quickly accessible. A survey was distributed online from February to April 2018 to collect data from seafarers (n = 107). The survey listed all functions included in Appendix 3 of document NSCR 5/7. With each function, survey respondents were asked to rate whether they believe the function should be accessible by single operator action, simple operator action, either single or simple operator action, or quick access not required at all. Results of this survey were submitted to the S-mode CG for consideration.

The S-mode CG also considered results from the survey on frequency of use for each function of an INS (Vu et al., 2019) and the eye-tracking study conducted by ROK (IMO, 2018c) that helped identify information on the displays of navigation equipment that is of interest to safe navigation.

Based on these results, minor changes were made to the initial list of quickly accessible functions. The revised list was presented in Appendix 4 of document NCSR 6/7 and subsequently approved as Appendix 4 of the S-mode guidelines (IMO, 2019b).

6.3.4. Default system settings for ECDIS and Radar

The fourth feature of the interfaces of navigation systems to be standardised by the S-mode guidelines is a set of default settings for ECDIS and Radar. These default settings are intended to provide a basic and minimal mode of operation, and users can quickly reset a system back to these default settings.

The first edition of this feature is included in Appendix 4 of document NCSR 5/7 (IMO, 2017a). the majority of the settings presented on this list were directly derived from existing performance standards, specifically: MSC.252(83) performance standards for INS (IMO, 2007b), IHO S-52 Presentation Library (IHO, 2010).

The S-mode CG did not conduct any usability study to evaluate whether these default settings would create a basic and highly usable mode of operation for Radar and ECDIS as intended. The group decided which setting would be suitable through internal discussions between members. Results from previous studies on user-preferred settings for Radar (Jacobson & Lutzhoft, 2008) and ECDIS (Lutzhoft et al., 2016) as discussed in section 6.1 were also taken into consideration. The groups also based their decisions on the goal of maintaining alignment between the S-mode guidelines and existing bridge equipment standards from IMO and IEC. Furthermore, given the time constraints, the same strategy used when making decision regarding the standard icons and terminology as discussed in section 6.2.1 was followed for the default system settings. If a setting did not immediately receive support from the majority of members and required further discussions/testing to reach agreements, such a setting would be removed from the S-mode guidelines. As a result, the final edition of this feature, included in Appendix 5 of the S-mode guidelines (IMO, 2019b), did not include as many settings as in the first edition.

To summarise, in the finalised S-mode guidelines, all settings that had already prescribed in previous standards were kept unchanged to maintain alignment with existing standards. For new settings not already prescribed in existing standards, the S-mode CG discussed and considered results of relevant published studies to make decisions on the most suitable setting.

This chapter has provided an overview of the work done to develop core contents of the S-mode guidelines – the four standard features to be applied for the interfaces of navigation systems. As with any IMO initiatives, the development of S-mode was a jointed effort of multiple stakeholders, each with own agenda and interests. As a result, there were non-technical factors that played a role in shaping the technical contents of the S-mode guidelines. The following chapter will discuss contextual factors that affected the development of S-mode.

7. Analysis and Discussion

Chapters 5 and 6 have summarised key events occurred during the development of the S-mode guidelines. Considering from the framework of joint activity, it is possible to group these key events into three phases, corresponding with the formation and execution of a joint activity. The three phases are as follow:

- Phase 1 – the main development of this phase was S-mode got accepted as an official part of e-Navigation, but there was no common goal among the involving parties. This phase started from the emergence of the S-mode concept and lasted until the adoption of the e-Navigation SIP in MSC 94, which gave S-mode an official place among e-Navigation solutions (IMO, 2014a). The participants involved during this period and their actions are discussed in sections 5.1 and 5.2.
- Phase 2 – the main objective of this phase was to determine a scope for S-mode. This phase began after the approval of S-mode as an e-Navigation solution in 2014 to the point when the scope of S-mode was finalised in NCSR 5 in 2017 (IMO, 2017a). Events happened during this phase and the involving actors are discussed in section 5.3.
- Phase 3 – the main objective of this phase was to finalise the contents of the S-mode guidelines. This phase began after NCSR 5 and ended when the S-mode guidelines were adopted in MSC 101(IMO, 2019a). The work done by the S-mode CG during this period is discussed in chapter 6.

This chapter discusses contextual factors affecting the development of the S-mode guidelines, considering perspectives of major stakeholders. These factors are presented following the chronological order of the three phases in the development of S-mode. The content of this chapter is a summary of the main points of Paper IV, currently under review at WMU Journal of Maritime Affairs (Vu, Lutzhoft, et al., 2022a).

For the convenience of readers, this chapter is structured to follow the chronological order of three phases in the development of S-mode.

7.1. The seeds of joint activity

As discussed in section 2.3, decisions made at the IMO are often influenced by politics and IMO negotiations could be interpreted as political contests between member states. Countries would enter a negotiation if a matter in question concerns their national interests and would use their influence at the Organisation to push for decisions aligning with their national agendas (Tan, 2005). A similar characteristic was observed in the development of S-mode, particularly in the negotiations taken to get S-mode adopted as an e-Navigation solution in 2014 (IMO, 2014a).

Since the first introduction of the S-mode concept to NAV 53 in 2007, the NI and IFSMA had aimed to get S-mode accepted as a part of the e-Navigation initiative. This motion was supported after studies by Germany, Canada, and the Republic of Korea indicating potential benefits of S-mode for mariners, particularly in facilitating training and familiarisation and improving equipment usability (IMO, 2009c, 2010a, 2010b). It was this support from IMO member states that helped S-mode enter the agenda of e-Navigation. On the other hand, manufacturers of navigation equipment, represented by the CIRM, had expressed disapproval toward S-mode since it was first introduced.

From the perspective of joint activity, it can be argued that a joint activity did not exist between the involved stakeholders during this first development phase of S-mode. There was no common goal shared among the stakeholders. The CIRM had no intention to develop S-mode and were working on other initiatives. The IMO members supporting S-mode mentioned in the previous paragraph were not specifically attempting to develop S-mode. Rather, they were working to develop e-Navigation and S-mode just happened to match some of the e-Navigation agenda items. Only the NI and IFSMA were interested in developing the S-mode concept. These three groups of stakeholders each pursued their goals independently and their actions were not interdependent. Considering the lack of both a common goal and a level of interdependence between the involved stakeholders, a joint activity did not exist during this time (Klein et al., 2005).

The process of getting S-mode accepted as an official e-Navigation agenda item can be interpreted as a political struggle between two groups, one supporting and one opposing S-mode. The turning point was NCSR 1 when both groups discussed and made the final decision whether to keep S-mode among e-Navigation solutions. The CIRM, IMPA, Japan, Netherland, and France did not support S-mode to be a part of e-Navigation while the NI, ICS, INTERTANKO, Denmark, Norway, Germany, ROK, Australia, Marshall Islands, Panama, Kiribati, Nigeria, Poland supported S-mode. Since the IMO works on a majority vote principle, the final decision was for S-mode to be a part of e-Navigation.

It has not been possible to determine the exact motivation behind each stakeholder's decision to support or disapprove S-mode. However, an interview with two major stakeholders suggests that S-mode received major support from two groups of organisations: those with strong crewing interest and developed coastal states. The former supported S-mode as improved equipment standardisation could make training of ship crews more efficient. This group included maritime nations with strong influence at the IMO. The latter group was interested in improving navigation safety in their waters and S-mode could serve that interest by improving the usability of navigation system and, thus, reducing the probability of erroneous actions made by ship crews.

The original S-mode concept was opposed by IMO members and organisations with strong interests in producing navigation equipment, especially the CIRM. While many complex arguments were made against S-mode, one persistent motivation from the manufacturers was that they wanted the freedom in designing their products by using innovative features as selling points. Considering the large number of manufacturers (as of February 2022, there were 105 members of CIRM) in such a small market as marine electronics, innovation and unique selling points are important to secure market share. Additionally, a standard interface could potentially lock in users, making it difficult for any subsequent change/update.

In summary, S-mode was supported by influential maritime nations and coastal states, and their support was instrumental in getting S-mode approved as an official IMO project. d

7.2. The start of joint activity

Following the acceptance of S-mode as an e-Navigation solution in NCSR 1, the next step was to decide a scope for S-mode – what to standardise and how? Viewing from the framework of joint activity, it can be argued that a joint activity started to emerge during this phase as there was a common goal and a degree of collaboration between the involved stakeholders, who formed the S-mode CG.

7.2.1. The formation of a common goal

Considering the first prerequisite of a joint activity, the involved stakeholders did share a common goal of determining a scope for S-mode. The stakeholders that participated during this period demonstrated a strong willingness to align their individual interests to maintain the joint activity. This willingness was observed on both stakeholder groups who had opposed and supported the inclusion of S-mode into e-Navigation during the first development phase discussed in section 7.1.

As the organisation representing manufacturers of navigation equipment, the CIRM acted to protect their members' interests. While opposed to the idea of fully standardised interfaces proposed by the original S-mode concept, the CIRM accepted that S-mode would be developed and wanted to be involved in the development process. The individual goal was to have manufacturers' inputs reflected in the outcome of S-mode since manufacturers would be the stakeholder obliged to implement S-mode in the end.

On the other hand, the stakeholders who had supported S-mode during the first development phase did not do so because they specifically supported the original S-mode concept. Interviews with representatives of two major stakeholders indicate that the goal of these stakeholders had always been to improve the standardisation of interfaces and level of usability for navigation equipment. They supported the original S-mode concept because, at the time, the concept was considered capable of bringing the desired level of standardisation and usability. However, these stakeholders acknowledged the importance of incorporating manufacturers' input and were willing to work with the manufacturers to find a solution agreeable to both parties.

It was this willingness to compromise from both groups of stakeholders that allowed a common goal to emerge. With the common goal of determining the scope of S-mode, the work was carried out in the form of workshops and negotiations as discussed in section 5.3. This form of collaboration meant the suggestions and arguments presented by each member of the S-mode CG were dependent on the suggestions and arguments made by others, thus creating a level of dependence between members.

While a joint activity did exist during this period, the collaboration within the S-mode CG was not always optimal and there were moments when members had conflicting opinions, hindering the collaborative efforts. The following section will analyse such moments through the concept of common ground.

7.2.2. Maintaining a strong common ground

As discussed in chapter 3.2.2, an important basis for effective collaboration in a joint activity is having a strong base of mutual knowledge, beliefs, and assumptions (Clark & Brennan, 1991).

At the beginning of the second development phase of S-mode, the common ground shared between members of the S-mode CG was limited to knowledge on IMO working procedures, the initial working plan for S-mode, descriptions of the original S-mode concept, and the objective of determining a scope for S-mode.

A common ground does not stay static but varies throughout the course of a joint activity and degradation can occur at certain points, hindering the collaborative efforts. In the case of S-mode, the main discrepancy occurred as members of the S-mode CG came from different backgrounds and had different perspectives on the scope of S-mode. Human factors specialists and maritime regulatory agencies envisioned S-mode as a set of human factors principles for designing interfaces of navigation systems. Manufacturers, represented by the CIRM, envisioned S-mode to be detailed specifications of certain features on the interfaces of navigation systems. Some members of the S-mode CG envisioned S-mode to take the form of a standard display for ECDIS with standard layout and menu structure. These differences in perspective explained why it took so long for the S-mode CG to decide on the scope of S-mode.

This degradation of the common ground occurred as most members of the S-mode CG, except for the CIRM, had limited knowledge of what manufacturers require from an implementable technical regulatory document. The group focused dominantly on studying the requirements of seafarers who are the end-users of navigation equipment while less focus was given to the need of equipment manufacturers who would implement S-mode directly.

Manufacturers, who dominantly come from engineering backgrounds, tend to approach knowledge in an empirical, pragmatic, and utilitarian manner (Koen, 2003). In the case of S-mode, the main concern of manufacturers when implementing a regulatory document is whether they can conduct tests to certify their products as compliant. To this end, manufacturers require detailed technical specifications with testable criteria. To manufacturers, the human factors principles, which were developed by human factors specialists and form the first part of the S-mode guidelines, were too generic to be implemented in actual design practices. In other words, other stakeholders had envisioned S-mode in a format incomprehensible or practically unusable for equipment manufacturers. This issue can be interpreted as a communication gap between manufacturers and other members of the S-mode CG.

This communication gap is not restricted to the case of S-mode but exists also in other IMO regulatory documents. An example is regulation V/15 of the International Convention for the Safety of Life at Sea [SOLAS], which regulates the design of the bridge, bridge equipment, and bridge procedures from an ergonomics viewpoint. The criteria set out in this regulation are sufficiently ambiguous that different classification societies have had different interpretations. Subsequently, the International Association of Classification Societies [IACS] has developed a unified interpretation of SOLAS V/15 (IACS, 2007).

Similar to SOLAS V/15, the case of S-mode serves as another example to demonstrate the communication gap between the implementors of a regulatory instrument and other stakeholders involved in developing such regulations. Such communication gaps cause regulatory instruments to be not fully implemented, or at least not to the intended level. In section 7.4, the author will argue that the structure and working principles of the IMO itself play a role behind these shortcomings.

7.3. Internationally-collaborative user-centred design

After the scope of S-mode was finalised in 2018, the S-mode CG started working to develop the contents of the S-mode guidelines. This work, as discussed in chapter 6, followed the principles of a user-centred design process. However, this development work was undertaken by an IMO correspondence group and followed the working arrangement of IMO correspondence groups. This chapter discusses aspects of such a working arrangement that shaped the conduct of user-centred design activities in the case of S-mode. It should be noted that the issues to be discussed can also occur in design projects in an industrial setting. The author of this thesis only emphasises factors in the working arrangement of an IMO correspondence group that caused the S-mode CG to make the decisions they made.

The first factor to consider is the fact that the S-mode CG, while attempting to follow standard steps in a UCD process as recommended in ISO 9241:2010 (ISO, 2010), did so in a loosely structured manner. This practice directly resulted from the working principle of an IMO correspondence group. Members of the S-mode CG carried out work on their own and communicated via emails with Australia acting as the coordinator.

In an industrial setting, for a user-centred design process to be successful, it is recommended that the application of user-centred design activities and methods be carefully planned and managed throughout the development process, and to maintain a good flow of information on users to the relevant parts of the development team (Maguire, 2001). Such recommended practices are not easily achievable within the working arrangement of an IMO correspondence group, specifically the S-mode CG in this case. Members of the S-mode CG did not have a detailed work plan which described the exact tasks to be carried out and methods to perform each task. The reason was that members joined the S-mode CG on a voluntary basis and each member was an organisation with its own resources and autonomy. Therefore, members of the S-mode CG, for the most part, decided on their own what they would do to contribute to S-mode. Although such decisions were communicated to other members and agreed upon, such practice resulted in a loose structure in the coordination within the S-mode CG. As a result, there was a lack of coherence in the way that the S-mode CG performed different user-centred design activities to develop S-mode. For instance, the first edition of the four interface features to be standardised by S-mode was developed by CIRM while NI and the ROK were still conducting studies to understand how seafarers operate navigation equipment in practice.

Another aspect of the working arrangement of an IMO correspondence group that influenced the development of S-mode was the methods of communication. Since members were physically located in different locations worldwide and communication was via emails, it took time to exchange ideas and reach agreements. With S-mode, a majority of the development work was undertaken by the NI, CIRM, Australia, and ROK. Their results were communicated to other members of the S-mode CG for feedback and decisions were made collectively. The use of email correspondence meant there were, in many instances, delays in information exchange between members, which affected the decision-making process. Combining with the deadline of 2019 given by the IMO, the S-mode CG had to adopt a negotiation strategy of "immediate consensus or nothing" when making collective decisions regarding the contents of S-mode, following the efficiency-thoroughness trade-off (ETTO) principles (Hollnagel, 2009). In order to meet the assigned completion date, the group essentially had to sacrifice the level of thoroughness in which the standard interface features introduced in S-mode were developed with usability in mind.

7.4. Maritime human factors and IMO regulatory regime

The development of the S-mode guidelines provides further insights into the status of human factors application in the design of shipboard navigation system as well as the role of the IMO in facilitating such practice.

7.4.1. Human factors consideration for shipboard navigation system

As discussed in section 1.1, there are still cases of shipboard equipment with usability issues, occurred due to the lack of human factors consideration during the design process. The development of S-mode and, at a higher level, e-Navigation, provides some explanation as to why this is the case.

One of the reasons could be that manufacturers are not able to effectively obtain user inputs to improve their products. In the first ten years following the emergence of e-

Navigation (2006-2016), manufacturers actively consulted seafarers through organisations such as the NI to study what user needs from shipboard systems to do their jobs. However, manufacturers often asked questions which were difficult for seafarers to answer. Common questions could be "*We have decided that we are going to give you a system that you want. What do you want? We will build it for you*" and the common reply from seafarers would be "*Just better stuff than we have*". Seafarers are not equipment designers and, therefore, cannot provide bridge system specifications that make sense to, and are immediately useful to, equipment manufacturers. Manufacturers had a vision for more sophisticated systems and were frustrated when seafarers could not explain what such systems would be like. This example demonstrates that manufacturers are not able to perform user-centred design effectively. It is possible that this situation can be connected to the absence of topics on human factors and user-centred design in curriculums for educating maritime system designers and naval architects (Abeysiriwardhane, 2017), and the difference in world views between human factors specialists and engineers (Petersen et al., 2011). This difference in perspectives between human factors specialists and engineers will be discussed in more details in section 7.4.2.

Additionally, to address human factors properly in an industrial setting, resources are needed. In the case of S-mode, from 2008-2014, the NI was constantly seeking resources from all potential sources to develop S-mode based on the original concept. The plan was to develop prototype interfaces for a wide range of displays on the bridge and test them with seafarers to identify optimal features for standardised interfaces. The NI estimated that 1 million pounds would be necessary for such a project and drafted a proposal to IMO member states. Some member states were interested, including Ireland, Singapore, Norway, and Canada. In the end, however, the budget plan did not get approved. The NI then changed the plan to develop web-based simulators, which would cost half the original budget to complete. This alternative proposal also did not receive funding. Ultimately, the whole research plan was abandoned due to a lack of resources and the NI could only perform a couple of online surveys to study user needs.

Another challenge with human factors engineering is the lack of a centralised approach for R&D in the maritime industry. Companies may have their own R&D department and flag states often invest through their national research institutions, but there is no industry-wide regime. In the case of S-mode, even as an international initiative, there was no central budget and stakeholders conducted much of the work independently using their own resources.

Finally, there is a lack of an effective communication channel between seafarers at the "sharp end" and people at the "blunt end" such as the IMO. Seafarers are practitioners with first-hand knowledge of current issues in shipping, especially when it comes to usability of shipboard equipment. They are represented by organisations such as the NI and IFSMA, but these organisations are not well-resourced enough to shape an influence at the IMO. At the same time, IMO delegates are often civil servants and even those with a technical background may have left the "sharp end" many years before joining the IMO and their experience is no longer relevant to understanding contemporary issues, especially with the current rate of technological advancement.

In summary, events during the development of the S-mode guidelines indicate that human factors is still an area requiring further development in the maritime industry, and regulatory instruments play an important role in facilitating such development.

7.4.2. The need for applicable regulatory instruments

Documents from regulatory agencies such as the IMO play a critical role in shaping directions in the maritime industry, maritime human factors included. There is little incentive for manufacturers to implement something without regulatory requirement. The fact that standard features introduced in the S-mode guidelines are mandatory significantly increases the impact of the guidelines.

As discussed in section 7.2.2, there existed a communication gap between equipment manufacturers and other stakeholders involved in developing technical regulatory documents. In the case of S-mode, it was mainly the gap between human factors specialists and equipment manufacturers with dominant engineering backgrounds.

To the author's knowledge, there was no published study investigating this communication gap in the context of marine electronics manufacturing. However, Bader and Nyce (1998) investigate a similar communication gap between social scientists and software developer. They observe that cultural and social knowledge, while provides useful insights on users, is not useful for software developers. The main reason is that social scientists and software developers perceive such knowledge differently, and the way researchers present their findings is not comprehensible for software developers. Petersen et al. (2011) use the term “two tribes problem” to refer to this problem. They explain that scientists and engineers belong to different groups (or tribes) of professionals, and reports of academic studies are drafted by people belonging to the scientist tribe following a format of scholarly writing which, while familiar to the scientists, does not make sense to people of the engineering tribe. A method to address this gap, as Petersen et al. (2011) suggest, is to initiative changes from the side of social scientists in the way studies are conducted and reported, aiming to generate knowledge comprehensible for the engineering community. To this end, it is suggested that researchers consider, in the conduct of studies on human factors-related subjects, both the end-users and the people who would implement the research findings. Transferring these findings from the context of software development to the context of marine electronics in the case of S-mode, it is important to consider both the end-users and equipment manufactures when developing relevant regulatory instruments. Specifically, for a regulatory instrument to be effectively implemented, it must be specific and contain testable criteria to evaluate compliancy.

The IMO, however, is not the most capable organisation for making technical documents. Especially in the case of technical documents on the topic of interaction design, the IMO tend to develop high-level regulations with generic criteria (Mallam & Nordby, 2018). IMO delegates are often civil servants, and they may lack the necessary experience to understand technical issues. When a technical matter requires comments/decisions from IMO members, the matter is often discussed at the national level and each member state will then give their delegates a script describing their agenda to be published at the IMO. Such published agendas tend to be generic and not targeting specific technical questions. The discussions whether to include or excluded S-mode among e-Navigation solutions during NCSR 1 as summarised in section 5.2 is an example of this practice.

Another factor to consider is that IMO meetings are not held frequently. Most of the meetings are annual and a lot of time passes between meetings. Also, IMO processes are inflexible and tightly controlled, with specific administrative procedures to be followed. On the one hand, this practice ensures a certain stability for the industry to function. If changes are made frequently, it will be very costly for the stakeholders to keep up with all the changes. Some stability is important as it helps to achieve some standardisation and allows people time to learn and be familiar with the new situation each time a change is adopted. On the other hand, however, such multiple-step processes do not support innovation and it takes a long time for new issues to come through at the IMO.

Furthermore, when considering unfamiliar topics, such as developing or implementing new technology, the IMO often begins with a low-level regulatory instrument like a guideline. If the industry progresses and perceives the guidelines as important, the IMO can raise the guidelines into a higher-level regulatory instrument such as a code or a resolution. For instance, human factors in digital interface design is an unfamiliar area for the IMO and, as a result, the IMO started with a guideline on human-centred design principles through document MSC.1/Circ.1512 (IMO, 2015d). The S-mode guidelines, with certain mandatory requirements, were a next-level step.

In combination, these factors make it difficult for IMO regulatory documents to get into the level of details and contemporaneousness that can facilitate human factors application in the industry.

On the contrary, technical organisations such as the International Association of Marine Aids to Navigation and Lighthouse Authorities [IALA] are formed mainly by people with technical backgrounds, have more frequent meeting sessions, and they work intersessionally. As a result, it would be best if the IMO focused on developing high-level performance standards, possibly goal-based, and technical organisations like the IEC or IALA developed detailed technical specifications. This approach is already in practice, but there are currently several technical organisations handling different topics – the IHO handles the ENC, the IALA deals with aids to navigation, and the marine department of the IEC deals with marine electronic systems. A more optimal structure for coordinating and regulating shipping at an international level could be achieved by merging all relevant technical organisations or at least joining them with regards to policy, resulting in a structure as illustrated in figure 3.

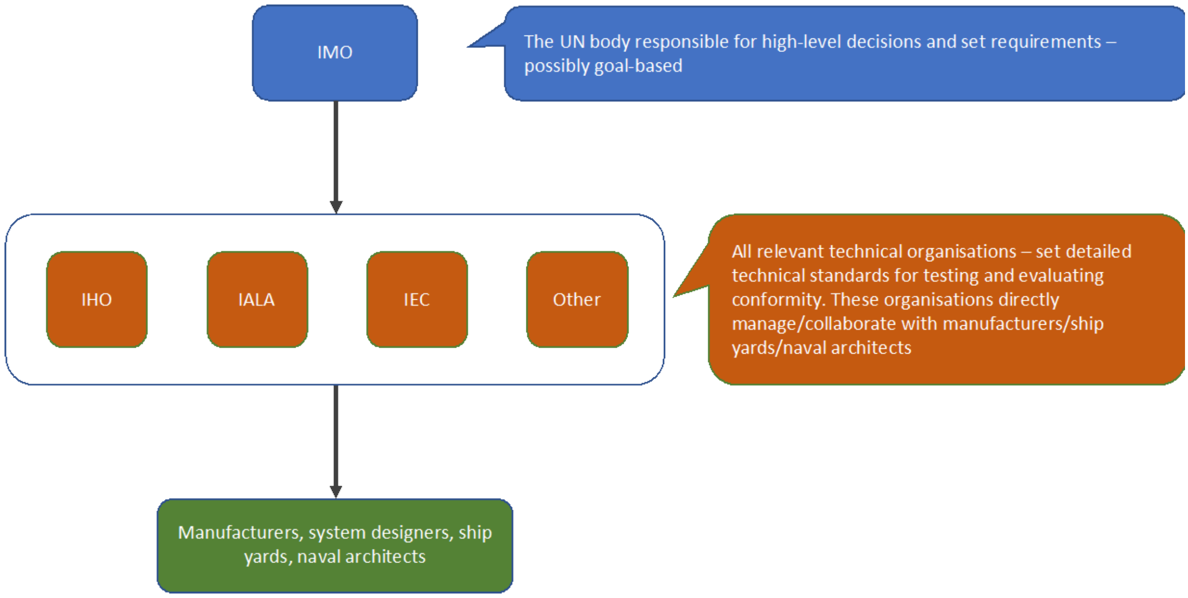

Figure 3. Suggested structure for organising stakeholders involved in developing and implementing human factors regulatory instruments in the maritime industry

In summary, the application of human factors in the maritime field, particularly in the design of navigation systems, is still limited. This status can be changed if manufacturers are given regulatory incentive while still having leeway for innovation. However, the working model of the IMO does not facilitate the development of detailed technical documents that meet the requirements of manufacturers. A better working model is for the IMO to focus solely on high-level regulatory instruments and collaborate with other specialised technical organisations such as the IHO or IEC to develop detailed regulations for manufacturers to implement.

Finally, changes happen slowly in the maritime regulatory field and any improvement needs to be implemented gradually, maritime human factors included. It is unrealistic to expect rapid or drastic changes.

8. Conclusions

This is the final chapter of this thesis. It starts with a summary of the main findings, followed by recommendations for relevant stakeholders, and concludes with implications for future research.

8.1. Summary of findings

The main findings of this study can be organised into two parts, corresponding with the two research aims. The first part contains knowledge on the context of use for shipboard navigation equipment and recommendations for the presentation of navigation-related information on navigational displays. Such knowledge can be used to develop or evaluate navigation equipment with usability in mind. The second part identifies contextual factors that shaped the development of S-mode. These factors should be considered when developing similar regulatory instruments in the future.

Information on the context of use for shipboard navigation equipment

- A summary of tasks performed by seafarers when engaging in navigation duties, together with information/function from navigation systems required to support each task. This result is presented in Annex 5 of this thesis
- Frequency of use for each mandatory function of a standard Integrated Navigation System, together with the purpose and scenario of use for each function. This result is presented in Paper 1, attached to Annex 1 of this thesis

Recommendations for the presentation of navigation-related information on navigational displays

- Some standard icons already prescribed in performance standards for navigation equipment are not easily comprehensible to seafarers, especially novice users. These icons are discussed in Annex 2 and Annex 7 of this thesis
- Essential contents on the interfaces of navigation systems should be organised in a logical manner which allows operators to locate and access important information with ease. A pattern was developed to group 48 essential functions of navigation systems into thirteen (13) groups. This pattern can be applied for a wide range of bridge equipment including ECDIS, Radar, and their

equivalent modules of INS. This pattern is presented in Paper III, attached to Annex 3 of this thesis

Factors affecting the development of the S-mode guidelines:

- Political support from influential maritime nations and coastal states was essential in getting S-mode approved as an IMO project
- While deciding the scope of S-mode, dominant focus was given to the end-users of navigation equipment – the seafarers. Meanwhile, little attention was given to manufacturers, who would be the implementors of S-mode. This communication gap between manufacturers and other members of the S-mode correspondence group hindered the collaborative efforts
- The working arrangement of an IMO correspondence group reduced the coherence and the effectiveness of communication between members of the S-mode correspondence group. Consequently, the group had to sacrifice certain level of thoroughness in their work in order to meet the assigned deadline

8.2. Recommendations for relevant stakeholders

- Human factors is still an area requiring further development in the maritime industry, and regulatory instruments play an important role in facilitating such development
- A successful regulatory instrument concerning human factors in designing maritime systems must consider the need of both the end-users and the implementors of said regulatory instrument
- The IMO is not the most capable stakeholder for making detailed technical documents that meet the requirements of manufacturers. The IMO should focus on generic high-level requirements and collaborate with specialised technical organisations to supplement such high-level requirements with detailed technical specifications
- Politics plays a major role in the decision-making at the IMO, and it is the large maritime nations that have the most influence over IMO decisions. Considering what happened with S-mode, similar initiatives in the future

should aim to secure support from influential IMO members to increase the probability of being adopted/endorsed at the Organisation

- The IMO follows a rigid and multi-step procedure for making decisions and changes happen slowly. Any improvement in the maritime industry needs to be implemented gradually, human factors included. It is unrealistic to expect or aim for rapid changes

8.3. Future research

This thesis contributes knowledge on context of use, which should be considered when developing or evaluating shipboard navigation equipment. At the same time, the thesis provides recommendations on the use of icons and the organisation of essential contents on navigational displays. However, these recommendations do not cover a whole range of functionalities available on navigation equipment but rather focuses on functions that support route monitoring and collision avoidance. Furthermore, while developing these design recommendations following a user-centred approach, the author did not conduct formal summative tests. Therefore, future research should aim to expand and formally validate the usability of these design recommendations. By expanding, the author suggests future research should address functionalities not included in these design recommendations, such as functions used for voyage planning. To validate usability, a method is to conduct summative evaluation of the design recommendations using high-fidelity prototypes with a sufficient sample of users (Kirakowski, 2005). Ideally, such summative tests should compare user performance between different prototypes, using metrics such as time taken to perform certain tasks.

The thesis also provides a detailed description of the development process for the S-mode guidelines, identifying the involved stakeholders and contextual factors that affected the process. However, this thesis concludes at the adoption of the S-mode guidelines in 2019 and does not concern the implementation step. There is a challenge with the IMO model in which IMO regulations do not require retrofitting for existing equipment. Since S-mode will enter into force on January 1, 2014, new navigation equipment produced after that day will comply with S-mode. Equipment manufactured before that date can potentially be updated to comply with S-mode, but this depends on the manufacturers. A more realistic vision, according to the CIRM, is that many ships will continue working with pre-S-mode equipment after 2024 and S-mode will be fully implemented after existing systems are retired, a process which might take at least ten years. By that time, technological advancements may change the way navigation is conducted onboard and existing design standards will require updates to stay aligned with contemporary navigation practices. Once again, the cycle of developing and implementing regulations repeats. It is proposed that this doctoral study be continued where it ended to understand the implementation of S-mode and how such implementation affects the maritime industry.

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Annex 1 – Paper I

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doi:10.1017/S0373463319000183

Frequency of use – the First Step Toward Human-Centred Interfaces for Marine Navigation Systems

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This article presents research on how frequently seafarers utilise functions and information available on an Integrated Navigation System to perform navigation duties. Using an online questionnaire, the study collected data from 601 members of the global seafaring community. The results provide an overview of the frequency of use for each feature, together with factors affecting the use and associated usability issues. The study finds that the use of navigation equipment is situation-dependent and affected by administrative factors, experience and professional habits, characteristics of the sailing area, traffic conditions, weather conditions, ship management factors and geographical location. Additionally, information overload, particularly with overlay and alert management functions, was found to be the major issue with existing systems. The findings of this study can be applied to improve menu tree structure, display layout, and interaction methods on the interface of navigation systems, such as making frequently-used features more readily available or easier to access.

KEYWORDS

1. Human-centred design. 2. Frequency of use. 3. Marine navigation systems. 4. User interface.

Submitted: 5 June 2018. Accepted: 10 March 2019.

1. INTRODUCTION. With the advancements of technology in marine electronics, traditional navigation instruments such as sextants and paper charts are being rapidly replaced by computer-based navigation systems. On one hand, this trend brings new facilities to assist people at sea. On the other hand, however, new equipment also creates new problems for the safety of navigation. Investigation into accidents such as the grounding of the *Ovit* in the Dover Strait in 2013 or the *Muros* on the east coast of the United Kingdom in 2016 raises concern about the potential negative effects of technology on safety (Maritime Accident Investigation Branch (MAIB), 2014; 2017). Reports from maritime agencies as well as academic studies indicate that electronic navigation systems, if designed improperly, could have adverse effects on human performance (Rowley et al., 2006; MAIB, 2008; Barsan and Muntean, 2010).

When developing marine electronic navigation systems, there are many instances where engineers focus primarily on technical aspects and do not adequately consider the needs and capabilities of users. Consequently, many systems are designed to be technologically functional but end up being difficult for users to operate, increasing the probability of erroneous actions (Grech et al., 2008). Another issue with existing navigation systems is the lack of a common design language among manufacturers. Products from different companies often have different "look and feel". Seafarers, whose job requires moving from one ship to another, face difficulties familiarising with new equipment when joining ships. The problem is even more serious for pilots, who often board several ships a day (The Nautical Institute, 2008).

To address this concern, the International Maritime Organization (IMO) started developing guidelines on standardised modes of operation (S-mode) as part of the e-Navigation initiative (IMO, 2015b). The basis of S-mode is a set of prescribed standards for several elements on navigation displays, focusing on the radar, Electronic Chart Display and Information Systems (ECDIS), and relevant components of Integrated Navigation Systems (INS). S-mode is expected to reduce diversity in design and, at the same time, improve the usability[1] of navigation systems (IMO, 2015b). To achieve the intended goals, S-mode must be developed to reflect the way seafarers work at sea. The research reported here was designed to contribute to the development of S-mode by studying how frequently seafarers use each feature of bridge systems. To collect data, an online survey, using SurveyMonkey software, was distributed to the global seafaring community with the support of the Nautical Institute (NI). The objective was to provide input to improve the usability of user interfaces in future navigation systems.

2. BACKGROUND.

The e-Navigation initiative was started as a strategy of the IMO to regulate the application of information technology to improve safety and efficiency in shipping. Among the intended benefits, e-Navigation aims to bring a user-centric approach to equipment design, which matches the system to "the characteristics of intended users and the tasks they perform, rather than requiring users to adapt to a system" (IMO, 2015a). Among the projects to implement e-Navigation, S-mode specifically concerns the user interface of navigation systems and aims to standardise several elements of the navigation displays, such as icons and terminologies or the grouping of information. Following the user-centric design approach of e-Navigation, S-mode intends to determine the optimal way to present functions and data on navigation systems, allowing seafarers to operate bridge equipment with ease. Being user-centric and standardised, S-mode is expected to bring the benefit of increased usability as well as reducing the effort needed in familiarisation with new equipment when moving between vessels.

The first step in developing S-mode is studying how seafarers work on board and identifying what they require from navigation equipment. However, until now few studies have been conducted to support the IMO S-mode project. Jacobson and Lutzhoft (2008) performed a study using questionnaires, interviews and workshops with participants from the Swedish defence and merchant navies to identify commonly-used settings for marine radar. This study was limited both in terms of sample size (56) and the study object (only radar

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[1] The concept of usability was introduced by Jakob Nielsen in his work "Usability Engineering" (Nielsen, 1993), to replace the ambiguous term of "user-friendly". In brief, "Usability" refers to the degree to which a system is easy, efficient and enjoyable to use.

was studied). A second study was carried out also using questionnaires to identify which bridge equipment and features should be standardised and explore the user-preferred layout of ECDIS displays (Lutzhoft et al., 2016). Another approach to determine the way seafarers interact with bridge equipment uses eye-tracking devices to track the navigator's eye movement patterns when engaging in navigation duties (Lützhöft and Dukic, 2007; Hareide et al., 2016; Hareide and Ostnes, 2017). However, existing studies can only determine different areas on the displays that attract users' attention but cannot precisely identify the dwell time for individual pieces of information (Hareide and Ostnes, 2016). Other studies were undertaken by the Comité International Radio-Maritime (CIRM) and members of the Navigation Working Group of the Sub-Committee on Navigation, Communications and Search and Rescue (NCSR) but their results are yet to be published (IMO, 2017). To the best of our knowledge, there has never been a study in the maritime context addressing the frequency of feature use – an important aspect of a user interface.

2.1. *Frequency of feature use in computer systems.* For computer-based systems, frequency of feature use is an important element for successful user interface design, determining the organisation of menu items, the display layout, and the method of user interaction (Shneiderman and Plaisan, 2004).

First, since most complex computer-based systems have a high number of available features, only a portion of which will be used often, having all functions simultaneously presented can lead to cluttered displays, and eventually information overload. Given humans' limited information processing capacity, it is necessary to prioritise functions on the interfaces. More frequently-used functions should be made readily available while functions with lower frequency of use can be eliminated from the interface and made accessible through secondary paths (Brown, 1998).

Additionally, as users gain experience with a system, they will benefit from a means to quickly access functions that are frequently needed (Nielsen, 1993). For this reason, functions with high frequency of use should be made accessible through advanced means such as shortcuts, hotkeys or macro facilities (Gong and Tarasewich, 2004).

Also, users of computer systems often need different functionalities for different scenarios. In the case of marine navigation systems, seafarers require different information for different tasks and navigational conditions. Adaptive user interfaces are interfaces that can automatically modify themselves to fit users' tasks and abilities, which can potentially reduce cognitive workload (Gajos et al., 2006). Data on frequency of function use can be applied to develop adaptive interfaces. By identifying information commonly needed in different scenarios, designers can create adaptive algorithms to make such information immediately available, once the corresponding conditions are met (Findlater and Gajos, 2009).

Without information on frequency of use, designers are forced to rely on their intuition, which, in many cases, contradicts user requirements and can lead to poor system usability (De Souza and Bevan, 1990).

To address this shortcoming, we conducted a survey to identify how frequently mariners use each of the features available on standard navigation systems. INSs are developed to support safe navigation by integrating navigational data from various individual equipments and provide the bridge team with centralised access to necessary functions and information. Even though not all vessels are equipped with an INS, the standard functions and information available on an INS are similar to those of conventional bridge systems. The difference is that an INS allows for centralised access to such navigation features.

3. METHOD. The survey consisted of 64 questions collecting users' ratings on the frequency of checking/operating/adjusting settings for features of INSs as specified in the performance standard for INS (IMO, 2007).

Following the IMO performance standards, INS functions and information are categorised into six task groups, namely Route planning, Route monitoring, Collision avoidance, Navigation control data, Status and data display and Alert management (IMO, 2007). Several INS features are listed under more than one task group.

In each survey question, we asked people to rate the frequency of use of an INS feature using a rating scale consisting of four frequency levels, namely "0-2 times in my whole career", "Once or twice in a voyage", "Once or twice a watch" and "Several times a watch". Respondents had the option to reply "Unclear question" if they found the question confusing and "Not applicable" if the feature was not available on their systems. Besides rating the frequency of use, participants could also write feedback on their experience using the feature in a comment box. This feedback was treated as qualitative data and was analysed separately from the frequency of use rating.

3.1. *Participants.* The survey was announced in issue 14 of The Navigator – a publication of The Nautical Institute that is specialised in promoting professional seamanship, published in 2017. The majority of the participants, therefore, were assumed to be readers of the magazine. The authors also specifically contacted seafarers from the Australian Maritime College, Vietnam Maritime University, Odessa National Maritime Academy, Western Norway University of Applied Science and Dalian Maritime University to increase the number of participants.

3.2. *Procedure.* The survey was open between 1 February 2017 and 15 July 2017. The collected numerical data were processed automatically by SurveyMonkey and analysed using the Statistical Package for the Social Sciences (SPSS) version 22.0. The text answers were extracted manually into document files and analysed using the qualitative data analysis software NVivo version 11.

3.3. *Analysis.*

3.3.1. *Frequency of use rating.* After initial analysis, we found that the data were strongly skewed toward the category "Frequently during a watch" and decided to combine two categories "0-2 times in my career" and "Once or twice in a voyage" into a single category "Not used every watch". Three of the features were found to be "special cases" and their results will be discussed in the Findings section.

3.3.2. *User feedback.* Given the open-ended nature of users' feedback, an inductive approach allowed us to identify patterns and categories that emerged from the data (Thomas, 2006). For each feature, we read the comments several times to develop initial coding rules. We then started coding the data in NVivo following the initial coding rules and modified the coding as we proceeded. Each time we changed the coding rules, we re-read the coded content and modified the coded data accordingly. The process was repeated until no new theme emerged, at which a stage of inductive thematic saturation was reached (Saunders et al., 2017). At the end of the coding process, three major themes emerged from the data, namely "Conditions" – factors affecting the frequency of use of a feature, "Purposes" – the reasons for using a feature, and "Usability Issues" – difficulties encountered by seafarers when working with navigation equipment. The results allowed us to generate a descriptive overview of the way seafarers operate bridge systems, which is presented in Section 4 – Findings.

3.4. *Limitations.* In total, 601 seafarers of various levels of experience and areas of operation replied to the survey. However, the numbers of frequency votes varied between questions, ranging from 276 to 435, due to two reasons. First, many respondents preferred replying in comment boxes rather than using rating scales. Secondly, the gradual reduction of response rate throughout the survey shows survey fatigue to be a factor affecting the response rate at the end of the survey.

4. FINDINGS. We present the findings in the form of a guideline for manufacturers of marine electronics, structured into three parts: frequency of use, factors affecting the use and usability issues of existing navigation systems.

The findings are combined from the analysis of both quantitative and qualitative data. The numerical data allow us to establish an overview of how frequently seafarers use each INS feature, which is presented in Section 4.1. The qualitative user feedback provides a richer understanding of the use of each feature. Therefore, frequency of use should be considered in the light of the analysis of user feedback, which is discussed in Sections 4.2 and 4.3.

4.1. *Frequency of use.* As discussed in Section 3, INS features were categorised into six task groups with some features serving more than one task (IMO, 2007). Following the same categorisation, we present results of frequency of use rating in Table 1, starting with features serving multiple task groups and following with features serving only a single task group. The grey colour is used to indicate categories with the highest number of votes. There were three cases where we were not able to obtain a clear frequency of use. These special cases are discussed in Section 4.1.1.

4.1.1. *Special Cases.*

4.1.1.1. *Search And Rescue Transponder (SART) and radar beacon signal processing function.* Paragraph 5.3.4 of the revised performance standards for radar equipment (IMO, 2004) requires X-band radar systems to be able to detect SARTs and Radar beacons in the relevant frequency band. However, the regulation also requires that it is possible to switch off those signal-processing functions, which will prevent X-band Racons and SARTs from being detected and displayed. A status should be indicated when these functions are turned off. The survey results show that the majority of responders were not aware of this feature and mistook this function with the routine testing and maintenance of SART units. However, this can also be interpreted as users almost never using this feature in practice.

4.1.1.2. *The active mode of steering or speed control.* This feature provides data for manual control of a ship's movement and is required under the provisions of paragraph 7.5.2.1 of the INS performance standards (IMO, 2007). When designing the survey, we changed the wording from "The active mode of speed and steering control", as in the regulation, to "The active speed mode" and "The active steering mode", which confused readers. Consequently, the survey received a high percentage of "Unclear" and "Not applicable" responses. The comments from users further demonstrate the confusion among respondents in interpreting the questions. Consequently, we have excluded these features from the report.

4.1.1.3. *Ice Data.* This feature is an optional function according to paragraph 7.3.3 of the INS performance standards (IMO, 2007). The survey showed that the use of this information significantly depends on the season and area of operation, and most respondents

Table 1. Frequency of use rating for INS features. The grey colour indicates categories with the highest number of votes.

Feature		Task	Frequency of use, expressed in percentage (number of responses)			Total number of responses
			Not used every watch	Once or twice a watch	Several times a watch	
Mode and status information		Route planning, Route monitoring, Collision avoidance, Navigation status and data display	13% (50)	51% (193)	36% (137)	380
Variable Range Marker (VRM)		Route planning, Route monitoring, Collision avoidance	7% (25)	21% (74)	72% (255)	354
Electronic Bearing Line (EBL)			7% (25)	20% (73)	73% (260)	358
Offset measurement of range and bearing			38% (126)	29% (99)	33% (111)	336
Radar/Chart Overlay		Route monitoring, Collision avoidance	35% (109)	37% (115)	28% (89)	313
The presentation of True scale ship symbol (optional feature)			20% (78)	25% (99)	54% (212)	389
Range scale display and adjustment	Checking the active Range scale		5% (19)	33% (140)	62% (262)	421
	Adjusting the range scale		5% (18)	32% (118)	63% (228)	364
Automatic Identification System (AIS) safety-related messages		Navigation control data, Status and data display	21% (77)	45% (168)	35% (130)	375
Navigational Telex (NAVTEX) messages			14% (52)	54% (193)	32% (115)	360
Voyage records		Route planning	59% (192)	33% (107)	8% (27)	326
The display of own ship's position and the selected route on the chart		Route monitoring	3% (12)	4% (19)	93% (394)	425

(*continued*)

Table 1. Continued

Feature		Task	Frequency of use, expressed in percentage (number of responses)			Total number of responses
			Not used every watch	Once or twice a watch	Several times a watch	
The display of Time-labels along a ship's track at selected interval	Displaying labels		24% (81)	28% (96)	48% (164)	341
	Adjusting the interval		52% (169)	35% (113)	13% (42)	324
The display of the Alternative Route			71% (212)	21% (62)	8% (25)	299
Route modifying tools and function to switch from the selected route to an alternative route			85% (277)	10% (33)	4% (14)	324
Function to display areas off ship's position (e.g. for looking ahead and planning) and return to own ship's position			11% (41)	27% (97)	62% (225)	363
Search-and-Rescue (SAR) and Man-overboard (MOB) modes			94% (299)	4% (13)	2% (7)	319
Manually adjusting the ship's position			75% (208)	16% (44)	9% (24)	276
Cross Track Error (XTE)			13% (55)	16% (66)	71% (293)	414
Function to find a point by entering coordinates or read the coordinates of a point			53% (177)	30% (102)	17% (56)	335
Display relevant symbols required for navigation purposes			25% (90)	33% (116)	42% (147)	353
The presentation of Radar and AIS targets		Collision avoidance	1% (5)	3% (14)	96% (409)	428
Function to filter AIS targets according to user-defined parameters			43% (139)	30% (97)	26% (84)	320
Target tracking and acquisition			11% (37)	14% (47)	76% (264)	348
Target information			2% (10)	12% (49)	86% (361)	429
Closest Point of Approach (CPA)/ Time to Closest Point of Approach (TCPA)			2% (6)	5% (18)	94% (365)	389
Bow Crossing Range (BCR)/ Bow Crossing Time (BCT)			8% (29)	11% (43)	81% (304)	376

(*continued*)

Table 1. Continued

Feature	Task	Frequency of use, expressed in percentage (number of responses)			Total number of responses
		Not used every watch	Once or twice a watch	Several times a watch	
Target Trails and Past Positions — Displaying target trails and past positions		11% (46)	23% (94)	66% (275)	415
Adjusting settings		30% (102)	41% (141)	29% (97)	340
Radar Bearing Scale		12% (45)	35% (133)	53% (203)	381
Fixed range rings		56% (193)	25% (87)	18% (62)	342
Parallel Index Lines (PI)		43% (150)	23% (80)	34% (119)	349
Trial Manoeuvre		66% (226)	23% (80)	11% (37)	343
Radar Gain and Anti-Clutter Functions		7% (24)	44% (161)	49% (179)	364
Radar performance optimisation and tuning (automatic/manual tuning)		43% (140)	39% (127)	18% (60)	327
Heading Line suppression function		53% (176)	27% (90)	20% (65)	331
Search and Rescue Transponder (SART) and Radar Beacons signal processing function		Special case			
Functions to enhance target presentation on the radar display		40% (126)	35% (112)	25% (80)	318
Latitude (LAT)/ Longitude (LON)	Navigation control data	4% (18)	26% (109)	70% (291)	418
Heading (HDG), Course Over Ground (COG), Speed Over Ground (SOG), Speed Through Water (STW)		1% (5)	4% (17)	95% (413)	435
Rate of Turn (ROT)		18% (71)	33% (126)	49% (189)	386
Under Keel Clearance (UKC)		24% (96)	24% (96)	51% (203)	395

(continued)

Table 1. Continued

Feature	Task	Frequency of use, expressed in percentage (number of responses)			Total number of responses
		Not used every watch	Once or twice a watch	Several times a watch	
Propulsion data		14% (51)	44% (155)	42% (149)	355
Rudder angle		7% (25)	21% (77)	72% (265)	367
Time and Distance to wheel-over or the next waypoint		8% (32)	31% (125)	61% (250)	407
Set and Drift		9% (34)	28% (109)	63% (240)	383
Wind direction and speed		2% (9)	27% (104)	71% (274)	387
The active mode of steering or speed control		Special case			
Ship's static, dynamic and voyage-related AIS data	Status and data display	58% (210)	30% (108)	12% (43)	361
Ship's relevant motion data		23% (79)	38% (133)	39% (135)	347
Sensor and source information		32% (118)	49% (183)	19% (72)	373
System configuration		90% (272)	6% (18)	4% (12)	302
Tidal and current data (optional feature)		29% (105)	48% (176)	23% (85)	366
Weather data (optional feature)		9% (32)	66% (238)	26% (93)	363
Ice data (optional feature)		Special case			
Alert management	Alert Management	11% (37)	27% (90)	62% (206)	333

have not experienced situations where this feature is needed. Consequently, we did not collect sufficient data to determine how frequently seafarers check this information when navigating in ice-infested waters. However, respondents did comment that this information would be critical for ice navigation. In all other conditions, Ice Data is never used.

4.2. *Factors affecting the use of navigation equipment.* Human variability and adaptability make it very difficult to analyse user interaction without considering the context of use, or as Sherwood Jones et al. (2006. P. 5) put it: "It all depends …". Interestingly, our analysis of word frequency using NVivo 11 finds "depends" to be the most common word used in users' comments. The survey results show that seafarers do not operate bridge equipment in the same manner all the time but rather adjust and adapt to the prevailing situation, as do many operators in time-critical or demanding operations (Woods et al., 2010; Rankin et al., 2014). Our research shows factors affecting the use of bridge equipment can be grouped into the following categories:

- Individual factors – experience-based decisions and professional habits
- Administrative factors – safety policies, procedures and checklists
- Characteristics of the sailing area – sea room to manoeuvre, navigation hazards, and depth
- Traffic condition – traffic density, traffic complexity and risk of collision
- Weather and sea conditions – all hydro-meteorological conditions of the area
- Ship management factors – voyage length, manager's instruction and specific operations
- Geographical locations – ocean waters, near-coastal areas, anchorages and port approaches

These influential factors are summarised visually in Figure 1.

In the following sections, we will discuss each category in detail.

4.2.1. *Administrative and individual factors.* It is a common belief in the maritime industry that "… accidents are preventable through following correct procedures …" (IMO, 2008). With the introduction of the International Safety Management (ISM) Code (IMO, 2018), the industry has become more proceduralised, and administrative measures such as policies, procedures and checklists have been developed as primary safety measures (Oltedal, 2011). The survey results show the explicit involvement of administrative factors in the way seafarers operate navigation equipment, as seen in an extract from users' feedback:

"*It all depends on the situation; we got most of these questions covered in our checklists/ route planning, it is clearly someone with less seagoing experience who has made these questions*" (ID 6193256832)[2]

Under normal conditions where there is no perceivable danger to the vessel's safety, the watchkeeper uses navigation equipment to periodically monitor the situation, plan for upcoming events and carry out recording duties. The way people operate bridge systems, in this case, is characterised by routine and non-routine inspection of information. Routine inspection follows safety procedures, and non-routine inspection is determined by the watchkeeper's evaluation of the situation, which in turn, is influenced by his/her experience and/or professional habits. The types of information of interest under these

[2] To protect the anonymity of our survey participants, the survey did not collect any personal data. We assigned a unique identification number to each respondent.

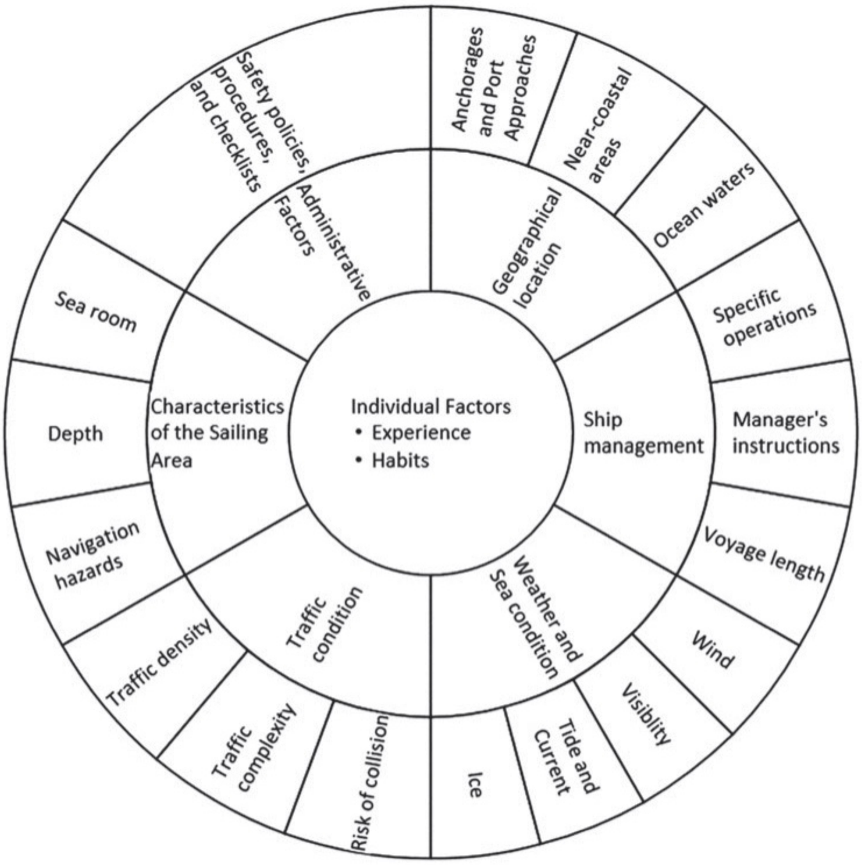

Figure 1. The main determinants of frequency of use for marine navigation systems.

circumstances belong to categories “Route monitoring information”, “Navigation control data” and “Status and data display” of INS task groups (see Table 2).

Most seafarers refer to these experience-based decisions and professional habits as “good sea practice” or “good seamanship”. However, while procedures and checklists can be traced back to shipboard Safety Management Systems (SMS) under the provision of the ISM Code, the nature of this study does not allow us to establish a clear understanding of what respondents referred to as “good seamanship”. Nevertheless, the results demonstrate that in general, seafarers answer that they operate navigation equipment *“... always as per the good sea practice and Company SMS procedures.”* (ID 6123532505)

In summary, under normal conditions with no perceivable dangers to the vessel’s safety, the main uses of navigation systems are to maintain situation awareness and record data. The information of interest, in this case, is data for monitoring navigation status of the

Table 2. List of INS features influenced by Administrative and Individual Factors.

Route monitoring information	Own ship's position and the active route as displayed on the chart
	Time-labels displayed along the ship's track
Navigation control data	HDG, COG, SOG, STW
	Rate of Turn
	Under keel clearance
	Rudder angle
	Time and distance to wheel-over or the next waypoint
Status and data display	Own ship AIS data
	Sensor and source information
	Tidal and current data
	Weather data
Navigation control data/ Status and data display	Navtex messages

Table 3. List of INS features influenced by the characteristics of the sailing area.

Interactive functions	VRM and EBL
	Adjusting range scale
	True scale ship symbol (especially for navigating in confined waters with limited sea room to manoeuvre)
	Displaying relevant symbols required for navigation purposes.
	Parallel Index Lines
Route monitoring information	The display of own ship's position and the active route on the chart
	The display of the Alternative Route
Navigation control data	LAT/ LON
	HDG, COG, SOG, STW
	Under keel clearance
	Propulsion data
	Rate of Turn, Rudder angle, Set and Drift (especially when navigating in confined waters with limited sea room to manoeuvre)
Status and data display	Tidal and current data

vessel and system performance. Users inspect such information both routinely, following safety procedures, as well as non-routinely based on personal judgement.

4.2.2. *Characteristics of the sailing area.* When the nature of the sailing area causes concern to the safety of navigation, seafarers start monitoring a wider spectrum of navigational information more intensively. Users' feedback shows particular concern regarding the available sea room to manoeuvre and depth of the surrounding waters as well as the presence of other navigational hazards. The main purpose of using navigation systems in these situations is to ensure that the ship does not run into danger. As a result, seafarers pay greater attention to monitoring the ship's position, taking into account external factors such as tides and currents, utilising active functions such as VRM or EBL to calculate and ensure navigation safety while considering alternative route options. Table 3 shows INS features more frequently used when navigating in areas with difficult characteristics.

In summary, when the characteristics of the sailing area are of concern, the seafarers' primary objective is to ensure that the vessel does not run into danger. The features of interest in this situation are the vessel's position, route information and other information

Table 4. List of INS features influenced by traffic conditions.

Interactive functions	Offset measurement of range and bearing
	Radar/ Chart overlay
	True scale ship symbol
	Adjusting interval between time labels displayed along the ship's track
	Displaying areas off ship's position (e.g. for looking ahead and planning)
	Filtering AIS targets according to user-defined parameters
	Fixed range rings
	Parallel index lines
	Trial manoeuvre
Route monitoring information	Cross Track Error
	The display of the Alternative Route
Collision avoidance information	The presentation of Radar and AIS targets
	Target information (both tracked and obtained from AIS)
	CPA/ TCPA
	BRC/ BCT
	Target trails and past positions
Navigation control data	Under keel clearance
	Time and distance to wheel-over or the next waypoint

Table 5. List of INS features influenced by weather and sea conditions.

In generic rough sea/ adverse weather scenarios:	The display of the Alternative Route
	Route modifying tools and function to switch from the selected route to an alternative route
	Manually adjusting the ship's position
	Radar Gain and Anti-Clutter functions
	Function for temporarily suppressing Heading Line
Specifically in restricted visibility:	Radar/ Chart overlay
	Adjusting target trails and past positions settings
Specifically in areas with strong and/ or variable current	Parallel index lines
	HDG, COG, SOG, STW

necessary to control the position relative to the planned track and navigation hazards in the vicinity

4.2.3. *Traffic conditions.* In difficult traffic conditions, the results show a surge in the use of features for collision avoidance, which indicates avoiding collisions to be the primary purpose of using bridge equipment in high-traffic areas. Seafarers actively utilise interactive functions and monitor relevant information to avoid close quarters situations as well as considering alternative route options. Table 4 shows INS features that are used more frequently in congested waters or under complex traffic situations.

4.2.4. *Weather and sea conditions.* The results show that in unfavourable weather and sea conditions, seafarers monitor weather data and forecasts more intensively, as demonstrated by increased observations of hydro-meteorological data. At the same time, several system functions will be used more frequently to avoid collisions or prevent running into hazards under the effects of adverse weather. Alternative route(s) can be displayed together with the active route for re-route consideration if needed. Table 5 shows INS features used more frequently under adverse weather.

4.2.5. *Ship management factors.* Factors such as voyage length, manager's instruction and specific operations such as tank cleaning play an insignificant role in the way seafarers operate navigation equipment but were mentioned in the user feedback. Specifically, a change to the passage plan may occur due to a manager's instruction or the need to conduct special operations, which in turn require a non-routine use of route modifying tools or adjusting AIS data. In addition, propulsion data will be monitored to ensure efficient fuel consumption.

4.2.6. *Geographical location.* Feedback from users indicate a clear distinction in the use of INS features between ocean waters and coastal areas. The frequency of use increases for almost all features when the vessel enters coastal areas, except for LAT/ LON data.

However, we also observed that the list of functions with increased frequency of use in coastal and harbour areas corresponds with the list of functions used more often in congested waters and areas with the presence of navigation hazards. Areas closer to shore usually have higher traffic density and their restricted depths give rise to the presence of navigation hazards. For that reason, we believe that this observed difference in frequency of use of bridge systems between geographical areas occurs due to the difference between traffic conditions and characteristics of those locations. However, the survey results do not provide us with sufficient data to analyse this matter in detail. Therefore, the influence of geographical locations on the use of navigation equipment will be investigated in subsequent studies.

4.3. *Usability issues.* Regulation V/15 of the International Convention for the Safety of Life at Sea (SOLAS) requires the design and arrangement of navigation systems and equipment on the bridge to be undertaken with the aim of allowing for continuous and effective information processing and decision-making while preventing or minimising excessive or unnecessary work which may distract or interfere with the vigilance of the bridge team and the pilot (IMO, 1974). However, through users' feedback, it is clear that seafarers still face information overload when working with existing navigation systems, particularly with Radar/Chart Overlay and Alert management.

4.3.1. *Radar/chart overlays.* Comments from survey participants show two general attitudes among seafarers toward the use of radar/chart overlays. The first group found the overlay feature useful and replied that they often use this feature if it is available on their systems. These seafarers reported using radar/chart overlay to:

- reconfirm the interpretation of the radar image
- check if there is a difference between radar echoes and chart objects to reconfirm the location of aids to navigation and check the accuracy of the Global Navigation Satellite System (GNSS) receiver

The second group of seafarers, on the other hand, commented that the overlay function does not work as expected with information overload being a major concern. These seafarers commented that the overlay feature often resulted in large amounts of data on the displays, making it difficult for operators to locate information. Additionally, there is the possibility that crucial information can be covered by non-crucial data.

"*I prefer to use radars and ECS/ECDIS separately. I am concerned about losing a target underneath a useless piece of charted data. Most cruise companies insist on combining radar overlay and an astonishing amount of data on the same screen*" (ID 6112984980).

"*. . . I find the chart overlay can cause information overload and sometimes the tracked targets are less visible with many data in background . . .*" (ID 6097265361).

User feedback indicates that the large amount of data displayed when the overlay feature is activated can be problematic to handle and consequently render the feature less useful. However, many users consider radar/chart overlay to be a useful tool to assist with navigation and thus, the feature can enhance safety at sea if the issue of information overload can be resolved.

While radar/chart overlay is a supporting feature, alert management is crucial to maintaining safe operation of the ship. For this reason, the usability issues with alert management will be discussed in detail in the following sub-section.

4.3.2. *Alert management.* The handling, distribution and presentation of alerts plays an essential role in facilitating situation awareness, supporting decision-making and improving the safety of navigation. The main purpose of alert management is to assist the bridge team in recognising an abnormal situation, identifying the origins of errors and deciding appropriate actions (IMO, 2010).

Regulatory documents require alert systems to be designed to avoid unnecessary distraction and reduce cognitive workload on the operators while, at the same time, being able to communicate necessary information (IMO, 2010). However, feedback from survey participants shows excessive alerts to be a frequently-encountered issue. Survey respondents commented that many models generate a large number of alarms, both visual and audible, which lead to information overload and can either hinder crucial information or distract the officer of the watch from attending to more important matters.

"The alarms are excessive on certain brands; annoying alarms replace pertinent manoeuvring or target data." (ID 6112984980)

"So many alarms all the time. More focus on this than anything else." (ID 620554563)

This is, however, not a new problem. Information overload due to redundant and superfluous alerts has been well documented in existing literature (Sherwood Jones et al., 2006; Motz et al., 2009). Several factors have led to an increased number of alerts in bridge systems, one of which is the integration of alert signals from external sources such as the Global Maritime Distress and Safety System (GMDSS) or the AIS. Additionally, most systems on the bridge are now computer-based, making it easier to introduce new alerts. This increased automation of bridge systems leads to the trend to introduce additional alerts without proper consideration of their operational impacts, especially following safety reviews (Sherwood Jones et al., 2006).

Although the issues with alert management facilities have been identified in previous studies, the results of this survey reaffirm that the problem is yet to be properly addressed. Given the importance of alert systems, information overload in alert management can have a serious consequence if not addressed properly, which is clear for the maritime as well as many other domains (Kerstholt and Passenier, 2000; Motz and Baldauf, 2007; Traub and Hudson, 2007). Since the survey did not allow us to reach respondents for follow-up questions, we were not able to investigate further into this matter. However, for the reasons stated above, it is suggested that subsequent studies on the usability of marine electronics should aim to address the issue of information overload, particularly in alert systems.

4.4. *Application of the survey results in design.* The findings of this research on the frequency of use for navigation functions and data can be applied to the user interfaces for marine electronics. A common principle in designing information architecture is that frequently-used features should be made accessible with the least operator action

(Shneiderman and Plaisan, 2004). This reminds us of the basic T arrangement of analogue flight instruments found in many aircraft cockpits, where the six most used flight instruments were placed in a T shape directly in front of the pilot (United States Department of Transportation, 2012). Infrequently used features, on the other hand, can be made accessible through secondary paths to avoid cluttering the display (Brown, 1998). However, infrequently used but essential features such as the SAR and MOB modes should still be readily available at all times.

Additionally, since the use of navigation equipment is situation dependent, users can benefit from an algorithm to adapt the interface to the prevailing circumstances. The concept of an interface capable of adapting to individual users or changes in situations is not a novel concept and has been introduced in other industries (Benyon, 1993; Langley, 1999). Within the maritime domain, Baldauf et al. (2009) proposed a similar approach to reduce the number of collision warnings. The basis of this is developing and applying an algorithm for self-adaptation of CPA limits according to current navigation settings, thus reducing the number of collision alerts activated as the vessel travels in near coastal areas where closer passing between vessels are expected. For a broader scope of the whole user interface, an adaptive interface may highlight or make ready the functions and data necessary for the current situation. Still, researchers face multiple challenges making the notion of adaptive user interfaces viable, which are outside the scope of this study.

5. CONCLUSION. This article presents the results of a survey on the frequency of use for functions and information available on integrated navigation systems. The frequency of use for each feature should be used as input for designing menu items and display layouts on the interfaces of navigation equipment. For instance, frequently used features should be made readily available or easily accessible. Additionally, the survey shows that the use of navigation systems is situation dependent, and seafarers require different sets of functions and information for different scenarios. Factors affecting the frequency of use include:

- Individual factors – include experience-based decisions and professional habits
- Administrative factors – include safety policies, procedures and checklists
- Characteristics of the sailing area – include available sea room for manoeuvre, depth and the presence of navigation hazards
- Traffic condition – includes traffic density, traffic complexity and risks of collision
- Weather and sea condition – includes wind, visibility, ice, tides and current conditions
- Ship management factors – include instructions from managers, voyage length and specific operations such as tank cleaning or ballast water exchange
- Geographical location – includes ocean waters, near-coastal areas and anchorages and port approaches

To improve usability, systems should be provided with a means to adapt to situations, such as a self-adaptation algorithm for highlighting information necessary under the prevailing circumstances.

Information overload was reported to be the major usability issue with existing bridge systems, especially with radar/chart overlays and alert management. Respondents were concerned that this issue could make it harder to identify crucial information or alternatively distract the officer of the watch from attending to more important matters. Although this is not a new issue, this survey reaffirms that the problem has not been properly addressed.

This is the first of a series of studies conducted to specify user requirements when working with navigation systems in order to provide input to the IMO guidelines on Standardised modes of operation (S-mode). In subsequent studies, we will investigate factors affecting frequency of feature use identified in this study as well as other aspects of user interfaces that influence the way seafarers operate navigation equipment.

The development of modern marine electronics has introduced a new way of working on board ships and brought additional assistance to the navigator. However, improper design can make users expend more mental effort to control navigation systems effectively, causing negative effects on their overall performance. Optimal system design must include actions to improve human-computer interaction, allowing the mariners to handle all essential information and take full control of the situation with ease. To achieve this aim, bridge systems must be designed following a user-centric approach, taking into account the requirements of intended users within the context of use.

ACKNOWLEDGEMENTS

This research was conducted with great support from the Nautical Institute. We also want to show our gratitude to all the seafarers and maritime researchers who took the survey and provided invaluable data for this study.

ETHICAL STANDARDS

This project was approved by the Tasmania Social Sciences Human Research Ethics Committee under the Ethics Reference Number H0016285.

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Annex 2 – Paper II

Standard icons for function controls on navigation systems – design and issues

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Abstract - **Icons are graphical images used to represent processes or functions on the interfaces of electronic systems. Effective icons must be easily comprehensible for users. Within the maritime domain, icons used on navigation systems are subjected to technical requirements. However, there is no study investigating the comprehensibility of such standard icons. Face-to-face interviews and an online survey were conducted to evaluate standard icons specified in the performance standards. The results show issues with a number of standard icons prescribed in IEC 62288:2014. Specifically, icons from three groups: a) standard Panel Illumination and Display Brilliance icons have optional features that reduce icon concreteness, b) icons for display orientation modes lack specification for the Course Up mode and the proposed icon is not sufficiently distinctive, c) the standard icon for Radar Performance Monitor depicts a concept familiar to equipment manufacturers but unfamiliar to users.**

Keywords
Navigation systems, graphical user interface, icon design, usability.

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INTRODUCTION

In electronic systems, icons are pictographic representations of functions and processes that support dialogues in human-computer interaction (Gittins, 1986).

The use of icons takes advantage of the capabilities of the human brain, which allows us to process imagery information faster and recognise previously-encountered images more accurately compared to words (Horton, 1993; Paivio, 2013). Additionally, icons take up less space than text commands - saving space for other display elements on the interfaces.

Within the maritime field, icons are widely used in modern navigation systems such as Radar and Electronic Chart Display and Information Systems (ECDIS).

Despite the advantages, however, icons must be designed to convey the intended messages successfully. Studies on icon design have identified several icon characteristics to affect user performance and inadequate icons can be difficult for users to identify or locate (Ganor & Te'eni, 2016; McDougall, De Bruijn, & Curry, 2000).

In 2015, the International Maritime Organisation (IMO) started developing the Guidelines for the Standardisation of User Interface Design for Navigation Equipment, known unofficially as the S-mode Guidelines. The guidelines provide several regulations for the design of user interfaces for marine navigation systems, including a new set of standard icons for navigation functions and data. During the development process, the S-mode working group (hereby referred to as "the SWG") reviewed icons already in use for navigation systems as required by technical standards and found several them to be improperly designed.

This article discusses three cases of such inadequate icons, detailing design principles that those icons violate and the effects on users.

BACKGROUND

The development of the S-mode guidelines is a part of the IMO e-Navigation initiative, which regulates the future utilisation of information technology to improve safety and efficiency in shipping (IMO, 2008). The S-mode guidelines specifically target the design of user interfaces for navigation systems, aiming to improve usability and decrease diversity in the design of navigation equipment among different manufacturers (Jacobson & Lutzhoft, 2008).

To achieve its purposes, the S-mode guidelines standardise two features of navigational systems: terminology and symbology (icons), and the arrangement of information on the displays (IMO, 2018).

The new standard icons contained in the S-mode guidelines were developed following a human-centered design approach. The icons were subjected to tests and design iteration to ensure their usability.

At the time of developing the S-mode guidelines, many icons used on navigation systems were already regulated by technical performance standards, among which are the IEC 62288 standards for the presentation of navigation-related information on shipborne navigational displays, issued by the International Electrotechnical Commission [IEC] (2014). However, there was no official document on the development of such standard icons and there was no published research to demonstrate their usability. As a result, the SWG decided to include those icons in their tests.

Factors affecting icon usability

For an icon to be usable, it must be comprehensible to users. Studies in pictograph interpretation have found several factors that affect the comprehensibility of icons. Such factors can be separated into three categories, namely those that concern the design of the icon themselves, those that concern users, and the operational context.

Characteristics of individual icons include concreteness, complexity, and semantic distance. Additionally, icons are seldom presented in isolation, making distinctiveness an important characteristic.

Concreteness refers to the degree to which an icon resembles real objects, material, or people. Concrete icons are easier to interpret than abstract icon. Complexity refers to the number of visual details of an icon and has no effect on icon comprehensibility, but complex icons have negative effects on users' visual search performance. Semantic distance represents how closely an icon is related to the underlying concept and significantly affects the accuracy of icon interpretation among new users. For icon groups, a principle in icon design is minimising shared features between icons performing different functions while maximising shared features between icons of the same family (Kurniawan, 2000).

Regarding user characteristics, there are three factors affecting the ability to recognise icons; familiarity, domain knowledge, and cultural background.

Familiarity refers to the frequency of which users encounter an icon (Ng & Chan, 2008) or the frequency of which users encounter the object depicted in the icon (McDougall & Curry, 2004). Familiarity significantly improves the accuracy of icon interpretation (Shneiderman & Margono, 1987). Knowledge of the referent concept and cultural background also influences the interpretation of icons (Strauss & Zender, 2017; Zender & Cassedy, 2014).

Finally, context influences the interpretation of icons. The meaning of an icon is created by combining the icon image, the characteristics of the observer, and the context (Horton, 1994). However, for the tests discussed in this article, context was excluded due to complexity. Only icon and user characteristics were considered.

TEST METHODS

Two tests were carried out to assess icon usability. The first was face-to-face interviews with users and the second was an online survey.

Five master mariners took part in the interviews, three from India and two from Denmark. During the interviews, the icons were shown to each participant one by one, the first time without the associated labels and the second time with the labels. For each icon, the participant was provided basic context such as the equipment or the type of functionality and asked to interpret its meaning. The interviewer asked follow-up questions to explore the reasoning behind the interpretation. The participants were encouraged to provide additional comments regarding the design of the icons in question and suggest alternative icons if desired.

The online survey followed the reverse approach to the interviews. The survey showed participants a function and asked them to select among three available options the most suitable icon. Regardless of the answer, the survey would then reveal the meanings of all three icons, and participants could provide additional comments if desired. The number of respondents differs between questions, ranging from 27 to 45.

RESULTS AND DISCUSSION

A total of 59 icons were tested during the development of the S-mode guidelines. However, this article only discusses icons that were standard at the beginning of the S-mode development process.

The results show that many of those standard icons do not always convey their intended meanings. Those icons are regulated by IEC 62288 and belong to three function groups: setting up brightness level, setting up display orientation, and Radar performance monitoring.

The following sections present results and discuss issues with those icons.

Panel Illumination and Display Brilliance – the issue of concreteness

Panel Illumination and Display Brilliance are used to adjust brightness level for the control panel and the display screen respectively. IEC 62288 (IEC, 2014) provides standard icons for these two functions, as presented in Figure 1.

Panel Illumination Display Brilliance

Figure 1. Panel Illumination and Display Brilliance icons

According to IEC 62388, both Display Brilliance and Panel Illumination icons have a circle surrounding the main symbol, and this circle is optional (IEC, 2014). We included these circles in all our tests.

In our first test (the interviews), four out of five participants associated the two icons Display Brilliance and Panel Illumination with the concept of brightness adjustment. However, the fifth participant could not make sense of the symbols. He commented that he recognised the main symbol but could not make sense of the surrounding circle and, therefore, could not identify the object being depicted.

Results from the interviews raised the concern that the circle surrounding the main symbol in the two icons Display Brilliance and Panel Illumination could make the symbols less similar to real-life objects and reduce the concreteness of these two icons.

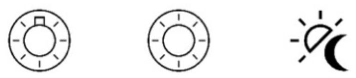
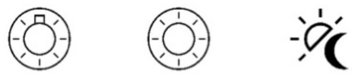
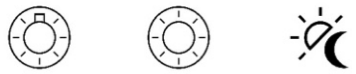
To further investigate if the circles were an issue, we proceeded with the second test using the online survey. In the survey, the icons Display Brilliance and Panel Illumination were compared to the icon for switching display colour combinations. This function is used to provide the best viewing in daytime, night time, and twilight, as presented in Figure 2:

Day/Night

Figure 2. Icon to select Day/Night/Twilight colour mode

Results of the survey are presented in Table 1

Table 1. Survey results for three icons Panel Illumination, Display Brilliance, and Day/Night colour modes (bold numbers highlight the most-selected option).

Which of the following Icons represents the function for setting Panel Illumination?		
		
10 (33%)	2 (7%)	**18 (60%)**
Which of the following Icons represents the function for setting Display Brilliance?		
		
9 (21%)	15 (35%)	**19 (44%)**
Which of the following Icons represents the function to toggle between Day/ Night/ display mode?		
		
2 (5%)	1 (3%)	**34 (92%)**

All three icons under discussion represent functions related to brightness/contrast adjustment and all three depict objects associated with the concept of light. Icon Panel Illumination resembles a lightbulb, icon Display Brilliance resembles the sun, and icon Day/Night resembles the sun and the moon. However, the Day/Night icon does not have a circle surrounding the main symbol.

Results from the survey clearly show that people are more likely to associate icon Day/Night with brightness adjustment than the other two. The circles in the two icons Display Brilliance and Panel Illumination caused the icons to be more abstract and reduce their comprehensibility.

Display Orientation

There are three orientation modes for Radar; North Up, Head Up, and Course Up. The IEC 62288 provides standard symbols for the North Up and Head Up modes (IEC, 2014), presented in Figure 3:

North Up Head Up

Figure 3. Icons to select North Up and Head Up display orientation

There is no standard icon for the Course Up orientation. As a result, manufacturers are free to select an icon for this mode, which can lead to a lack of consistency between manufacturers and the potential use of inadequate icons. It is, therefore, necessary to develop a standard Course Up icon.

Using the principles in designing icon groups set out by Kurniawan (2000), the standard Course Up icon must share similar design features with the North Up and Head Up icons while maintaining sufficient distinctiveness. To address this matter, the Comité International Radio-Maritime (CIRM) proposed a standard icon for the Course Up orientation as presented in Figure 4.

Course Up

Figure 4. The proposed Course Up icon

The SWG conducted tests to evaluate the suitability of this proposed icon.

In the first test (the interviews), one out of five participants correctly identified the Course Up icon. The other four participants interpreted the symbol as True Motion, Heading Line or Range.

The proposed Course Up icon uses a dotted arrow to depict the ship's course, and by having the line pointing up, the symbol refers to the Course Up orientation. However, based on feedback from the interviewees, these are also the features that confused them. The dotted line signifies motion, and in combination with the arrowhead, the dotted arrow was interpreted as the depiction of the ship moving forward, leading to the impression of True Motion. The dotted line was also interpreted as disappearing, and when combining with the arrowhead, the symbol was interpreted as the function to temporarily suppress the Heading Line. Additionally, the dotted line also signified distance measurement, causing one interviewee to interpret the icon as range measurement (Variable Range Marker). Results from the interview sessions indicate that the proposed Course Up icon did not clearly convey the message of Course Up orientation.

In the second test (the online survey), icon distinctiveness was evaluated. Results of the survey question are presented in Table 2.

Table 2. Survey results for three icons North Up, Head Up, and Course Up (bold numbers highlight the most-selected option).

Which of the following Icons represents the function to select the Head Up orientation mode?		
		
6 (14%)	**20 (47%)**	17 (40%)
Which of the following Icons represents the function to select the Course Up orientation mode?		
		
0 (0%)	9 (31%)	**20 (69%)**

The survey results show that the proposed Course Up icon can easily be confused with the standard Head Up icon. The differences between the two are not significant enough to maintain satisfactory distinctiveness. Based on results from both the interviews and the survey, the proposed Course Up icon was not adopted into the S-mode guidelines.

Still, it is necessary to develop a standard Course Up icon to avoid diversity between manufactures. However, the SWG could not develop a suitable Course Up icon within the limited timeline. As a result, the SWG decided to use text labels instead of icons for all three orientation modes.

Performance Monitor

The IEC 62288 provides the standard icon for Radar Performance Monitor switch, see Figure 5.

Performance Monitor

Figure 5. Standard icon for Radar Performance Monitor

Performance Monitoring is a mandatory radar function that helps monitor and detects performance drop (IMO, 2004). This function works based on the following principle: the radar transmits a pulse to an object known as the echo box, mounted on a designed place onboard. This echo box is constructed and positioned in a way so that the energy re-radiated from it resembles returning radar signals from normal targets, despite its proximity to the radar receiver. The returning signal from echo box produces a visible response on the radar display, called performance monitor signal, and is used to monitor and detect any performance drop on the radar (Bole, Dineley, & Wall, 2005). Examples of such performance monitor signals on a Radar manufactured by Raytheon Anschutz (2014) are provided in Figure 6.

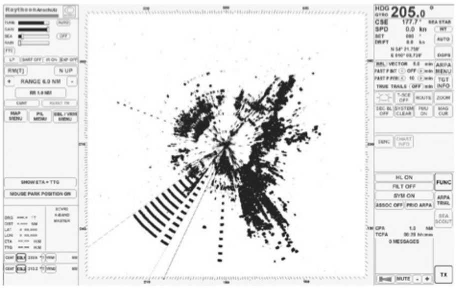


Figure 6. An example of performance monitor signals displayed on the Radar screen

In the interviews, none of the participants could recognise the icon as Performance Monitor. One participant commented that the symbol resembles a ship under rolling motion but could not understand the icon. The other four participants could not recognise the symbol. After the icon's meaning was revealed, all participants commented that the symbol has no visual cue to Performance Monitoring.

The icon did not perform well in the online survey either as 48% of the respondents did not correctly identify the Performance Monitor icon.

As mentioned in the Background, familiarity significantly affects icon interpretation. The standard icon as per IEC 62288 illustrates the working principle of the Performance Monitoring function. It depicts the transmitting and receiving of performance monitor signals from and to the antenna. Engineers who build and repair radars are familiar with this concept. To a seafarer, however, performance monitoring simply means observing and evaluating images of the Performance Monitor patterns displayed on the radar screen, as illustrated in Figure 6. The standard Performance Monitor icon has low comprehensibility because it depicts a concept unfamiliar to users.

While the SWG could not develop an alternative icon due to time constraint, the issue with this icon was forwarded to the IEC to be addressed in subsequent performance standards.

CONCLUSION

During the development of the Guidelines for the Standardisation of User Interface Design for Navigation Equipment (unofficially known as the S-mode Guidelines) as part of the IMO e-Navigation initiative, usability tests were conducted on standard icons used in navigation systems. The icons are specified in performance standards IEC 62288:2014. Issues were found in three icon groups that cause the icons to be difficult for users to interpret.

The icons for Panel Illumination and Display Brilliance have optional design features that reduce their concreteness and consequently their comprehensibility. It is, therefore, recommended that the circles be removed completely from the icons in the performance standards.

Icons for Display Orientation lack provision for the Course Up orientation, which can potentially lead to unnecessary design diversity. The proposed Course Up icon failed to maintain sufficient distinctiveness and, on its own, did not successfully convey the message of Course Up orientation. While the proposed icon was not adopted, the SWG could not develop a suitable alternative. Therefore, it was decided that text labels, instead of icons, would be used for all three Display Orientation modes.

Icon for Radar Performance Monitoring function depicts a process familiar to Radar manufacturers but unfamiliar to users. Consequently, many users cannot interpret the symbol. This issue was forwarded to the IEC to develop solutions in subsequent performance standards.

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Annex 3 – Paper III

Logical grouping of data and control functions on the displays of shipboard navigation systems

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Abstract

Standards IEC 62288:2014 and MSC.191(79) require information on the displays of shipboard navigation systems to be logically grouped, but only provide limited specification for this "logical" criterion. Meanwhile, complex interfaces and information overload remain as major design issues, being connected to several maritime accidents. To address the matter, a three-phase study was conducted to develop a pattern to organise essential information on the displays of Radar and ECDIS and their equivalent modules on INS and IBS. The first phase involved identifying information most essential for safe navigation using cognitive task analyses, equipment performance standards, and frequency of use. The second phase involved a card-sorting experiment with seafarers (n = 63) to develop an initial grouping pattern for the identified essential information. The third phase involved validating the initial grouping pattern with a new sample of seafarers (n = 35). The result is a pattern to group 48 information of shipboard navigation displays into thirteen groups. This article details the selected methods, the findings, and provides implications for future research.

1. Introduction

On September 18, 2013, the Maltese-flagged chemical tanker Ovit ran aground in Dover Strait. Subsequent investigation found two contributing factors related to the use of Electronic Chart Display and Information System [ECDIS] onboard. Firstly, the safety contour settings were inappropriate for the vessel's draught. Secondly, the safety zone feature[1] was incorrectly configured and the alarm, which could have alerted the officer of the watch [OOW] of the shallow waters ahead, was disabled (MAIB, 2014).

Three years later, on December 3, 2016, the Spanish-flagged general cargo vessel Muros ran aground on the Haisborough Sand in the North Sea. Similar to the case of the Ovit, it was also found that the safety zone feature was not activated (MAIB, 2017). It should be noted that both the Ovit and Muros, at the time of their respective accident, were equipped with the Maris ECDIS 900[2].

A number of similar accidents, where incorrect use of ECDIS was involved, gave rise to the term "ECDIS-assisted accident" (Nielsen, 2016). Reports of such "ECDIS-assisted accidents"

[1] This is mandatory function of an ECDIS, as per clause 11.4.2 of document MSC.232(82). However, there is no official term for this function and different labels are used, depending on the manufacturer. Common names include safety frame, safety route check, look ahead, anti-grounding, and guard zone
[2] Maris ECDIS 900 was manufactured by the Norwegian firm Maritime Information System AS. The firm no longer exists as it was acquired in 2014 by Navico, who also owns the brand Simrad. Model ECDIS 900 is still manufactured but currently under the brand Simrad

often list the ECDIS operator as the main culprit as he/she has not operated the system in the manner intended by the manufacturers and the vessels' managers (MAIB, 2008, MAIB, 2012, MAIB, 2015). However, a study by researchers from Lund University finds operators' errors to be connected to design issues, especially the complexity of system interfaces and information overload. Information is not intuitively organised, and operators must navigate through complex system menus and sub-menus to locate required features. Furthermore, there is too much information presented and unnecessary data are often included, which can potentially become clutters (Nielsen, 2016). Together, these design issues make it difficult for the operators to work effectively and increase the chance of errors.

To help mitigate these design issues, the authors conducted a research to develop a pattern to organise contents on the displays into groups so that seafarers/operators can access important information with ease. In this article, the term *grouping pattern* is used to refer to a way to organise different information, control functions, and settings available on the displays of navigation systems into various groups. Given the limited resources available to the research team, the scope of this research is limited only to Radar and ECDIS displays, and their equivalent components in Integrated Navigation Systems [INS] or Integrated Bridge Systems [IBS]. Also, this research only concerns equipment on SOLAS vessels.

This article details the selected methods, the findings, and provides implications for future research.

2. Previous studies and findings

There have already been academic studies and regulatory documents concerning the organisation of information on navigation displays, although the number is limited. In specific, standards IEC 62288:2014 (IEC, 2014) which, together with document MSC.191(79) (IMO, 2004a), require data and control functions on the interfaces of navigation systems to be logically grouped based on the functions or tasks. The documents also provided examples of grouping patterns for main Radar functions, but such groups are only suggestive, and the authors could not find any source validating or evaluating the usability of such patterns. Additionally, these documents do not specify exactly how a grouping pattern can be considered "logical" and only stated that such criteria shall be confirmed by "analytical evaluation" (IEC, 2014, p. 16).

Document MSC.1/Circ.1609 (known unofficially as the "S-mode guidelines") introduces another grouping pattern for essential information. Compared to IEC 62288:2014, the pattern introduced in the S-mode guidelines contains more generic data and can be applied for a wider range of navigation equipment. Also, unlike the IEC pattern, this S-mode pattern is mandatory, and equipment manufactured after 2024 must follow (IMO, 2019). Still, the S-mode grouping pattern only includes a limited number of navigational data, and the usability of the grouping pattern has not been evaluated.

Regarding academic studies, the few number of researches on the organisation of contents on navigation displays all employ eye-tracking devices to record the eye movements of the operator while navigating, either on a real ship or in a simulated environment (IMO, 2018, Hareide, 2019). All these studies share common drawbacks. With eye-tracking data, it is only possible to identify screen areas that users most often gaze upon, without understanding the reasoning and/or intention of users. Additionally, there is a difference between unintentional gazing upon a screen and actively searching the screen for information, and it is difficult with eye-tracking data to distinguish between those two actions.

In summary, there are both industry guidelines and academic studies on the grouping of contents on navigation displays. However, all these studies have weaknesses and none of their findings were validated with users. Also, all existing studies fail to capture the reasoning/intention of users. As a result, there is a need for a research approach that can developing a grouping pattern, collect data on users' reasoning/intention, and validate the grouping pattern using appropriate usability methodologies.

3. Methods

As this research aims to improve the usability of an interactive system, an user-centred design approach is deemed most appropriate as similar design projects has found the approach to be effective in creating systems with high usability (Petersen, 2010). The authors design this research to follow standard user-centred design activities, as prescribed in standards ISO 9241-210 (ISO, 2010).

In specific, the research contains three phases, each with own methods.

3.1. Phase 1 – Identifying the context of use

The first step of this research is identifying the context of use, which involves identifying characteristics of the users, the tasks to be performed, and the working environment (ISO, 2010). Specifically in this case, it is necessary to identify the tasks involved when seafarers navigate ships and the functions on Radar and ECDIS required to support each task.

To achieve the objective of this phase, the authors perform three activities:

- Review performance standards of navigation systems to identify minimum mandatory functions
- Review existing analyses of navigation tasks, addressing the weaknesses of each analysis, and merge results of all available analyses together into a single analysis of navigation tasks
- Conduct a survey to collect data from seafarers on the frequency of use [FOU] for each function of a standard INS, together with the purpose of each function

The first activity involves reviewing performance standards for marine navigation systems to identify mandatory functions. As per the scope of this research, only performance standards for Radar (IMO, 2004b), ECDIS (IMO, 2006), and INS (IMO, 2007) were considered. This action was taken to account for the variety in design and functionality of systems between different manufacturers.

The second activity involves reviewing analyses of navigation tasks. The research team has originally planned to perform a new task analysis but eventually changed the plan after considering two factors. Firstly, there have been several analyses of navigation tasks done both in academia and in the industry, and all of them have limitations. Secondly, conducting a new comprehensive analysis is time- and resource-consuming, even more so if the authors attempt to account for the limitations of previous analyses. As a result, the research team decided not to conduct a new analysis, but rather to review existing analyses, accommodate their shortcomings, and combine the results together. Given the advancement of navigation techniques overtime, the analyses done by Sanquist, Lee and Rothblum (1994), Røed (2007), Procee et al. (2017), Van Westrenen (1999), and Koester, Anderson and Steenberg (2007) were considered. The research team has taken the following measures to address the shortcomings of these analyses:

- The analyses were conducted in different moments throughout a long period of time. As a result, some of the identified tasks reflect out-dated practices, many of which have been automated or modified. To address this issue, the research team identified such out-dated practices and revise them using literature on contemporary nautical practices

(IMO, 2004b, Swift, 2004, IMO, 2006, IMO, 2007) as well as reflecting on the experience of the researchers, all of whom were seafarers. An example is the task of computing Target Relative Motion and True Motion Vectors by plotting on the Radar PPI, as described in the analysis by Sanquist et al. (1994), has long been automated by ARPA

- Many existing task analyses have limited scope, such as area of observation, people observed, or having specific operational contexts such as high-speed crafts (Røed, 2007). To address this issue, the research team identified such specific tasks and removed or adapted them to conventional navigation scenarios. This step was taken using two sources of reference. The first one is, once again, literature on contemporary nautical practices and the experience of members of the research team. The other reference is results of the survey on FOU[3] for standard functions of INSs, which will be discussed in subsequent sections
- All existing analyses lack details in some of the identified tasks while giving sufficiently detailed descriptions for others. To address this issue, the research team merged all analyses together, allowing the merits of one analysis to accommodate for the shortcomings of another. Results of the FOU survey were also used to add details to under-specified tasks

The third step involves a survey on the frequency of which seafarers use each function of a standard INS when performing navigation duties. The survey also collected data on the purpose of each function and scenarios in which the functions are utilised, with results collected from 601 seafarers worldwide. Details of the survey and the results are published in an article by Vu, Lützhöft and Emad (2019).

In the end, results of the three activities described above were combined to create a comprehensive picture of how seafarers operate navigation systems. The results help identify functions of Radar and ECDIS most essential for safe navigation and should be readily available on the displays.

3.2. Phase 2 – Developing an initial grouping pattern

Once the context of use is established, the next step should be identifying users' requirements. In this case, it is necessary to understand how seafarers perceive and categorise information when engaging in navigation duties and organise the contents, which were identified at the end of phase 1, into groups in a manner so that seafarers can access necessary information with ease.

To these ends, the researcher do so using a method called "Card sorting", which originated from the Q methodology developed by Stephenson (1935) to study subjectivity and is now commonly used by web designers and software developers to develop information architectures.

The method involves providing research subjects with a set of cards representing relevant concepts and having the subjects sort the cards into groups that are similar in certain ways (Wood and Wood, 2008). This method has been proven a simple yet useful method to gain insight into how users categorise and organise information (Faiks and Hyland, 2000, Gatsou, Politis and Zevgolis, 2012, Doubleday, 2013)

In this project, the card sorting was conducted in the form of unmoderated open sorting using an online platform at www.usabilitest.com. Each research subject was given 49 cards

[3] Frequency of Use

representing 49 functions of Radar and ECDIS that are essential for safe navigation. The authors use the term "functions" to refer to a piece of information, a control function, or a setting that is presented on the displays of Radar and ECDIS or their equivalent modules on an INS. These 49 functions were selected based on the results of Phase 1, and the number of 49 cards was selected after several pilot studies to achieve the most completeness of data while also preventing the research subjects from being fatigue. A complete list of these cards is attached to Annex 1.

The card sorting was advertised with the support of the Nautical Institute and research subjects are the Institute members, who are also maritime professionals. Grouping patterns created by the research subjects (n = 63) were merged using a statistical classification technique called Advanced Merge Method (AMM), to create a single grouping pattern. See Vu and Lutzhoft (2018) for details.

The grouping pattern resulted after phase 2, hereby referred to as the "*initial grouping pattern*", represents a collective mental model of all 63 research subjects regarding the classification of the 49 selected Radar and ECDIS functions. In this grouping pattern, the 49 selected Radar and ECDIS functions are arranged into twelve (12) groups. This *initial grouping pattern*, however, cannot be taken as a reliable final result due to the weaknesses of the card-sorting method used to create the pattern. Specifically, card sorting has the following weaknesses that must be considered:

- In card-sorting experiments, participants put content into groups (classifying). In actual usage scenarios, people look for information. There are differences between classifying and finding content (Spencer, 2009)
- Unless participants think out loud while sorting the cards, card-sorting cannot capture the rationale behind the grouping patterns (Maiden and Hare, 1998)
- Card-sorting does not produce concretely defined categories. It is very unlikely that research participants agree on everything and there will be disagreement at different extends in many cases. As a result, there is certain degree of intuition involved in the data analysis process (Brucker, 2010)

Considering these factors, the researchers developed a method to validate the *initial grouping pattern*, the details of which are presented in section 3.3.

3.3. Phase 3 – Validating the initial grouping pattern

Phase 3 involves validating the "initial grouping pattern" created at the end of phase 2. This step corresponds to the action of evaluating the initial design against user requirements in a standard user-centred design process (ISO, 2010).

Considering the limitations with card sorting discussed in section 3.2, the researchers decided to evaluate the "initial grouping pattern" using the following procedure:

1. The *initial grouping pattern* resulted from the card-sorting study in phase 2, which contained twelve (12) groups, was graphically illustrated as segments of Radar and ECDIS displays. The illustration can be seen in figure 1 with the groups numbered from 1 to 12. This illustration was designed as to not follow a design style of any specific manufacturer while still being sufficiently detailed to be recognisable by any person familiar with Radar and ECDIS

2. The researchers randomly selected seven (7) from the twelve (12) available groups, and deleted one item from each

3. The author showed the resulted twelve (12) groups to a research subject, who was a maritime professional. The subject was asked seven questions, each of which involved finding one of the seven missing pieces of content. The subject was instructed to point out, among the 12 available groups, the one he/she believed to most likely contain the missing items. Such groups, hereby, will be referred to as "*selected groups*". Each missing item could have several *selected groups* as the research subjects could have different mental models. The number of seven questions were selected after several pilot tests to ensure the subjects stayed engaged and maintained the thoroughness of their answers throughout the process
    i. All subjects were asked to explain their answers
    ii. If the subject believed he/she could not find the missing information anywhere among the 12 available groups, there was an option to select a "New Box"

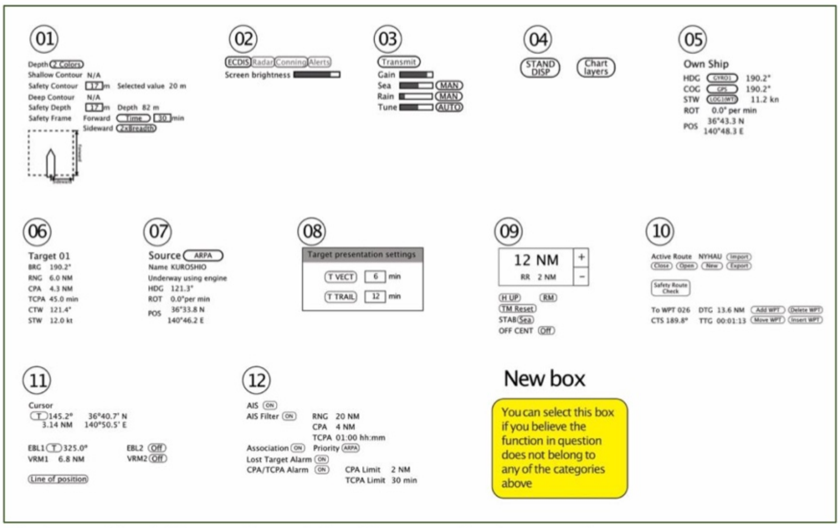

Figure 1. A graphical illustration of the 12 groups in the *initial grouping pattern*

4. The research subjects were randomly selected among professional networks of the researchers, and none of them had participated in phase 2 of this study. In fact, all but one subjects had never heard of this study until being recruited. In total, 35 subjects participated in phase 3 of this study. Demographic data of these research subjects are presented in Table 1.

Rank distribution	**Gender distribution**	**Average sea time**	**Nationality**
Master 63% (22) Chief Officer 14% (5) Second/Third Officer (7)	97% (34) male – 3% (1) female	17.2 years	Indian 66% (23) Vietnamese 14% (5) Norwegian 11% (4) German 6% (2)

Equipment Designer 3% (1)			Azerbaijani 3% (1)

Table 1. Demographic data of the 35 subjects participated in phase 3

5. Data collected from research subjects contained two types of information – the *selected group(s)* for each of the 49 Radar and ECDIS functions involved, and the reasons why these groups were selected. The researcher conducted thematic analysis following the inductive approach (Boyatzis, 1998) on the collected answers from research subjects to identify common themes among the reasoning of the subjects. The goal of this step was to determine, for each of the 49 selected functions, the most suitable group, hereby referred to as the "logical group". The term "logical" is used to stay align with documents IEC 62288:2014 (IEC, 2014) and MSC.191(79) (IMO, 2004a). However, since these documents do not specify this "logical" criterion, the authors set the criteria for a *selected group* to be considered the *logical group* was to be agreed by at least 80% of the research subjects. Subsequently, the identified *logical groups* would be compared with the *initial grouping pattern* to determine necessary revisions. Given this validation criterion, there were, for each of the 49 selected functions, three possible outcomes:
    i. The arrangement in the *initial grouping pattern* matched the *logical group* and no revision was needed
    ii. There was a *logical group* for the function in question, but it differed from the arrangement in the *initial grouping pattern*. In this case, the *initial grouping pattern* would be modified to align with new results
    iii. Research subjects did not agree on a *logical group* for the function in question. In this case, the researchers would analyse the reasoning behind the subjects' decisions, combined with results of the card-sorting experiment in phase 2 and usability principles set out in MSC.1/Circ.1609 (IMO, 2019) to determine the *logical group* and compare this result with the *initial grouping pattern*

In the end, the work in phase 3 resulted in a revised edition of the *initial grouping pattern*, hereby referred to as the "*revised grouping pattern*". The following section will present and discuss details of this *revised grouping pattern*.

4. Results

Following the revisions made after phase 3 of this study, the original 49 Radar and ECDIS functions were reduced to 48 as one function was founded to be incompatible with the rest. The removed function is the function to display time-labels at a selected interval along the ship's track, which is required under clause 11.4.12 of the performance standards for ECDIS (IMO, 2006). Results from both the validation study in phase 3 and the card-sorting study in phase 2 find this function to be incompatible with any of the remaining functions and should be placed in a separated group.

The remaining 48 functions were organised into thirteen (13) groups, listed in Table 2 below. Details of these groups are presented in the following sections.

No.	Group	Contents
1	Universal Presentation Settings (Fundamental)	Display mode indication (for MFD only)
2	*Should be placed near group "Universal Presentation Settings (Operational Display Area)"*	Screen brilliance level
3	Universal Presentation Settings (Operational)	Range scale/ Chart scale

4	*Should be placed near group "Universal Presentation Settings (Fundamental)"*	Range Ring scale
5		True Motion reset
6		Centred/Off-centred display
7		Orientation mode (NU/HU/CU)
8		Motion mode (TM/RM)
9		Stabilisation Mode & Stabilisation Source
10	Radar Display Settings	Radar system operational status (Standby/Transmit)
11	*Should be placed near group "Universal Presentation Settings (Operational Display Area)"*	Status (auto/manual) and level of Gain and Anti-clutter Control functions)
12	Chart Display Settings	Chart Display mode (Display Base/ Standard Display/ All)
13	*Should be placed near group "Universal Presentation Settings (Operational Display Area)"*	Chart Layer configuration (add or remove chart layers)
14	Chart Safety Settings	Anti-grounding zone (Look-ahead) settings
15		Safety contour settings
16		Safety depth settings
17		UKC
18	Target Settings	Target Trail Time and Mode indication
19		Target Vector Time and Mode indication
20	AIS settings	AIS processing status (On/OFF)
21		Status of filter for AIS targets together with filtering criteria (e.g., Range, CPA/TCPA, etc.)
22	Own-ship data	Own-ship HDG
23		Own-ship COG/CTW
24		Own-ship Rate of Turn
25		Own-ship SOG/STW
26		The source of own-ship's speed
27		Own-ship LAT/LON
28	Target Primary Data	Source of Target Primary Data (TT/AIS)
29	*Placed next to Target Secondary Data*	Target Range
30		Target Bearing
31		Target CPA
32		Target TCPA

33		Target Course
34		Target Speed
35	Secondary Target Data *Placed next to Target Primary Data*	Target Identification
36		Target Heading
37		Target Rate of Turn
38		Target Navigational Status
39		Target LAT/LON
40	Tools	EBL readouts
41		Bearing Reference Indication (True/Relative Bearing)
42		VRM readouts
43		Cursor readouts
44		Line of Position (LOP) control
45	Route Plan	Route plan management
46		Way-point management
47		Route validation (checking the route against hazards)
48	Alerts	Alert status and associated information

Table 2. The revised grouping pattern

The following sections will discuss details of each of the thirteen groups in the *revised grouping pattern*.

4.1. Universal Presentation Settings (Fundamental)

This group contains two (2) fundamental settings that configure the presentation of the Operational Display Area, as defined in MSC.191(79) (IMO, 2004a). In specific:

- Multifunction Display [MFD] Mode Indicator – this function is required under clause 7.1.1 of resolution MSC.191(79) (IMO, 2004a). It is only applicable for displays capable of presenting multiple functions, which are often found on Integrated Navigation Systems [INS]
- Brightness configuration

The settings contained in this group are "universal", in the sense that they are applicable to all displays of an INS including the Conning Display. In the case of conventional non-integrated bridges, the MFD Mode Indicator function is not applicable. The function for Brightness configuration, on the other hand, works similarly for both integrated and non-integrated systems.

There was no consensus among the subjects in phase 3 regarding the *logical group* for the MFD Mode Indicator. At the same time, 80% of the subjects placed Brightness Configuration in the same group with Rain and Anti-clutter Controls. The main reason is because the MFD Mode

Indicator is not available on non-integrated bridges, and it is rarely adjusted while Brightness is available on all systems, related to settings that adjust the presentation of the Operational Display Area, and is adjusted more frequently. However, the subjects in phase 3 also replied that seafarers often follow a common routine when setting up equipment, which involves the following steps:

- Turning on a system/ Switching a system from standby to operational mode/ Selecting an MFD Mode
- Adjust Brightness
- Configure other main system settings, which depend on the specific system in use

Considering this common set-up routine, and the fact that 56% of the research subjects in the card-sorting study in phase 2 placed these two functions together in one group, the authors decided that it is beneficial to grouped MFD Mode Indicator and Brightness Configuration into this group *Universal Display Settings (Fundamental)* and place this group near other presentation settings, which are discussed in the next section.

4.2. Universal Presentation Settings (Operational)

This group contains seven (7) settings that configure the Operational Display Area. The term "universal" used in labelling this group has a narrower sense as the settings of this group are only applicable to the Route Monitoring, Route Planning, and Collision Avoidance modules of an INS. On non-integrated systems, these settings are applicable only to Radar and ECDIS displays. The seven settings included in this group are:

- Range Scale/Chart Scale
- Range Ring Scale
- Centred/Off-centred Display
- Orientation Mode
- Motion Mode
- True Motion reset
- Stabilisation Mode & Source

Among these functions, Range Scale/Chart Scale, Centred/Off-centred Display, Orientation Mode, Motion Mode, True Motion Reset, and Stabilisation Mode & Source were grouped together by at least 80% of the research subjects in phase 3. This grouping pattern was due to the similarity in their functionalities, the frequency of use, and the natural workflow of most users.

Range Ring Scale was placed together with Range Scale/Chart Scale by 60% of research subjects in phase 3. There was one subject who grouped Range Ring Scale next to Electronic Bearing Line (EBL). The argument was because the subject frequently uses Range Ring Scale as a substitute for Variable Range Marker (VRM), and Range Ring Scale would be combined with EBL to roughly estimate positions of objects. However, this was not the mainstream opinion. Since Range Ring Scale is dependent on the actual Range Scale/Chart Scale in use and these two features are also grouped together by 60% of the subjects in phase 2, the researchers decided that it is logical to have Range Ring Scale next to Range Scale/Chart Scale.

One subject of the validation study in phase 3 guested Stabilisation Mode & Source would be grouped together with Ownship Speed as the Stabilisation Mode & Source determines whether Speed Over Ground or Speed Through Water will be displayed, and such was the arrangement on the subject's most recent vessel. However, this was not the mainstream opinion. 60% of the subjects guested that Stabilisation Mode & Source would be found in the group that contained

Orientation & Motion Settings while another 20% grouped this function with Brightness Settings as both are related to the Operational Display Area and both are rarely adjusted. Considering the mainstream opinion of subjects in phase 3 and the fact that Stabilisation Mode & Source was also grouped together with Orientation Mode, Motion Mode, True Motion Reset, and Centred/Off-centred Display by 60% of the subjects in phase 2, the researchers decided that it is logical to have Stabilisation Mode & Source in the same group with Orientation and Motion Settings.

Also considering the common workflow mentioned in section 4.1, this group *Universal Presentation Settings (Operational)* should be placed near group *Universal Presentation Settings (Fundamental)*.

4.3. Radar Settings

This group contains two (2) settings to configure the Operational Display Area of Radar systems, which are:

- System operational status (Standby/ Run)
- Status (automatic/ manual) and level of Gain and Anti-clutter Control functions

This group contains fundamental Radar settings, which are usually set up right after the Radar is switched on. To facilitate the common workflow mentioned in section 4.1, this group should be placed next to both groups *Universal Presentation Settings (Operational)* and *Universal Presentation Settings (Fundamental)*.

The label "Radar Settings" is selected for this group to follow the standard set out in table 6 of document MSC.1/Circ.1609 (IMO, 2019).

4.4. Chart Display Settings

This group contains two (2) settings for the presentation of the chart on ECDIS systems. These two settings are:

- Chard Display mode (Display Base/Standard Display/All other information) – this function allows users to quickly select a chart display mode. The Standard Display mode selector is mandatory, as required by clause 5.3 of performance standards for ECDIS (IMO, 2006).
- Chart Layer configuration (add or remove chart layers) – this function allows users to manually select which chart information to be displayed. The function is required by clause 5.5 of performance standards for ECDIS (IMO, 2006)

The settings in this group are often set up right after the ECDIS is switched on. To facilitate common workflow, this group should be placed next to both groups *Universal Presentation Settings (Operational)* and *Universal Presentation Settings (Fundamental)*.

The label "Chart Display Settings" is selected for this group to follow the standard set out in table 6 of document MSC.1/Circ.1609 (IMO, 2019).

4.5. Chart Safety Settings

This group contains four (4) chart-related safety parameters. The label "Chart Safety Settings" is selected to align with document MSC.1-Circ.1609 – Table 6 (IMO, 2019). The four features included in this group are:

- Look-ahead settings – this function raises an alarm if the vessel, given her course and speed, will enter dangerous waters. The function is mandatory, as required by clauses

11.4.3, 11.4.4, 11.4.6 of ECDIS performance standards (IMO, 2006). There is no standard name for this feature and different manufacturers use different terms, including Own-ship check, Safety Frame, or Anti-grounding. In this article, the term "Look ahead" is used

- Safety contour settings
- Safety depth settings
- Under-keel Clearance [UKC]

Results of the validation study during phase 3 indicates that the subjects categorised settings of navigation systems based on the purpose of the settings, the technical nature of the setting, and the frequency of adjustment. An example is with Safety Contour. The subjects' opinions were divided into two approaches: based on the use of the setting (to avoid grounding) and based on the technical nature of this setting (as an ENC layer). 60% of the subjects selected the first approach and grouped Safety Contour Settings with other depth-related settings, especially Safety Depth Settings. The other 40% selected the second approach and grouped Safety Contour with other chart layer settings, placing it in group *Chart Display Settings* discussed in section 4.4.

The researchers decided to keep Safety Contour Settings in this group *Chart Safety Settings* instead of *Chart Display Settings* because Safety Contour, as required by MSC.232(82) is a part of Base Display and must be permanently shown on the screen. Users cannot remove this information from the chart. Furthermore, Safety Contour Settings and Safety Depth Settings are rarely adjusted. Chart Layer Settings, on the other hand, are adjusted more frequently. Users would actively enable or disable certain layers to create the most suitable chart display for the prevailing situation. Also, Safety Contour Settings and Safety Depth Settings were grouped together by 92% of the subjects in the card-sorting study in phase 2.

Another example is with UKC. Technically, this is a part of own-ship data as it is depended on the vessel's draught. However, this information is also depth-dependent. In the validation study in phase 3, 80% of the subjects placed UKC with Safety Depth and Safety Contour settings while one 20% placed UKC among other own-ship data such as Course, Speed, and Geographical Coordinates. The argument was that users would often need to check UKC in a scenario where the depth might be a safety concern.

4.6. Target Settings

This group contains two (2) settings that configure the presentation of Targets on the Radar displays. The label "Target Settings" is selected to align with document MSC.1-Circ.1609 – Table 6 (IMO, 2019). The two features included in this group are:

- Target Vector Time and Mode settings
- Target Trail Time and Mode settings

These settings are directly related to Targets but, in a broader term, are also related to both the configuration of the Operational Display Area and to other safety settings.

This group should be placed near group *Universal Presentation Settings (Operational)* discussed in section 4.2 as it is a common workflow to adjust Target Settings after setting up the Operational Display Area.

This group should also be placed near Target Data as users often adjust values for Target Trailing Length based on data of concerning Targets.

4.7. AIS Settings

This group contains settings that configure the display of targets retrieved from Automatic Identification System [AIS], which is the dominant source of Target Data on ECDIS. These settings include:

- AIS Processing Status (On/ Off)
- AIS filtering criteria

The setting for target association, while not included in this study, was also mentioned by research subjects to be a part of this group. Subjects reported a common setup workflow starting with switching on AIS processing, followed by adjusting filtering criteria, and finally setting up Target Association settings.

This group should be placed near group *Target Settings* discussed in section 4.6 as the settings in both groups are related to the presentation of Targets on the displays.

There already exists a standard grouping pattern for AIS presentation status set out in resolution MSC.191(79) (IMO, 2004a), which corresponds with this *AIS Settings* group. These results indicate that the standard grouping pattern for AIS settings, set out in MSC.191(79), matches the common workflow of users.

4.8. Ownship Data

This group contains Ownship Data generated from shipboard sensors, which include:

- Own-ship Heading [HDG]
- Own-ship Course [COG/CTW]
- Own-ship Rate of Turn [ROT]
- Own-ship Speed [SOG/STW]
- The source of own-ship's speed
- Own-ship coordinates [LAT/LON]

The content of this group received strong consensus among research subjects. All subjects in the validation study in phase 3 support this grouping pattern. With the card-sorting study in phase 2, HDG, COG/CTW, ROT, SOG/STW, and LAT/LON were grouped together by 84% of the research subjects. The source of own-ship's speed was included into the same group by 60% of the subjects.

4.9. Target Primary Data

Target Data are available from both Automatic Radar Plotting Aid [ARPA] and AIS. Results from both the card-sorting study in phase 2 and the validation study in phase 3 indicate that, for each target, some data are more important than other and should be readily available at all times while other are less critical and not always required.

This section presents Target Primary Data, which are essential for safe navigation and should be readily available. These six (6) pieces of data include:

- Target Range
- Target Bearing
- Target CPA
- Target TCPA
- Target Course
- Target Speed

- Source of Primary Target Data

Target Primary Data can be calculated using ARPA or fetch from AIS. All subjects involved in the validation study in phase 3 commented that ARPA would be the preferable source for Primary Data. Target Secondary Data, to be discussed in section 4.10, originate solely from AIS.

4.10. Target Secondary Data

Target Secondary Data are those that are not essential for collision avoidance and do not need to be readily available. These five (5) pieces of data all originate from AIS and include:

- Target Identification
- Target Heading
- Target Rate of Turn
- Target Navigational Status
- Target LAT/LON

Among Target Secondary Data, Target Identification and Target Heading received diverse feedback from research subjects.

With Target Identification, 60% of the subjects in phase 3 grouped it in Target Secondary Data while the other 40% grouped this information among Target Primary Data. The argument of the latter group was that, for ease of communication, the operator would require the name and/or call sign of the target vessel readily available. The counter argument of the former group was that contacting other ships for collision avoidance would be inadvisable and rarely carried out. Also, most systems do display the name of AIS-activated ships next to the AIS icon of that ship on both ECDIS and Radar Displays. Considering these arguments, the researchers decided to place Target Identification among Target Secondary Data.

Similarly, with Target Heading, 60% of the subjects in phase 3 grouped Target Heading among Secondary Data while the other 40% grouped it among Primary Data. The latter group argued that Target Heading determines the applicable rule(s) of the road and, therefore, is an important information. The former group counterargued that Target Heading information is transmitted from AIS of the target ship, and it is not possible to verify the integrity of the information received. In addition, Target Heading is not essential for determining the rule of the road to be used as the officer of the watch (OOW) can do so by looking over the windows and observe the target ship visually. Considering these arguments, the researchers decided to place Target Heading among Target Secondary Data.

4.11. Tools

This group contains tools to aid with navigation and collision avoidance. The five (5) functions included in this group are:

- EBL readout
- Bearing Reference Indication (True/Relative Bearing)
- VRM readout
- Cursor readouts
- Line of Position [LOP] controls

Within this group, the grouping of VRM, EBL and Cursor Readouts received a general consensus from at least 80% of the research subjects in phase 3. On the other hand, there were diverse opinions regarding the grouping of Bearing Reference Indication and LOP controls.

With Bearing Reference Indication, the subjects' opinions were divided into two approaches. The first approach, selected by 60% of the subjects, was grouping this function with EBL and cursor readouts as all these features are related to Bearing and users often need to adjust Bearing mode only when operating EBL. The second approach, selected by 40% of the subjects, was to group Bearing Reference Indicator with other presentation settings in group *Universal Presentation Settings (Operational)*. The argument was that Bearing Reference Indication usually serves also as the control to switch between True and Relative Bearing Mode, and such setting is considered a presentation setting.

Both approaches have no effect on the way EBL is used as users can always recognise whether True Bearing or Relative Bearing is being used by looking at the value of EBL readouts. It was decided that Bearing Reference Indication be place together with EBL and Cursor readouts in this *Tools* group because this approach received more support from research subjects (60% of the subjects in the validation study in phase 3 and 61% in the card-sorting study in phase 2).

With LOP controls, 60% of the subjects in phase 3 placed this function together with EBL and VRM due to the similarity between these two. The other 40% of the subjects placed this function in group *Chart Display Settings* discussed in section 4.5. However, these subjects commented that they were familiar with such arrangement on their previous vessels and there was no other reason for their answers. As a result, these answers could have been influenced by recency bias. Considering this factor, the researchers decided to place LOP controls together with EBL and VRM in this “Tools” group.

It should be noted that, in document MSC.1/Circ.1609, the Cursor Readouts is placed in a separated group called “Cursor Location” while EBL and VRM are grouped together in a group called “Measurement Info” (IMO, 2019, p. 29). Still, there is no part in this document where it is specified that these two groups *Cursor Location* and *Measurement Info* cannot be placed together in the same head group. As a result, the results of this study do not contradict document MSC.1/Circ.1609.

4.12. Route Plan

This group contains function used for making/adjusting Routes by creating/editing Waypoints or by browsing existing routes in the Route Database. This group received a general consensus from research subjects and contains the following items:

- Route plan management/ Route Database
- Way-point management tools
- Route validation (checking the planned route against hazards)

All subjects in phase 3 selected this grouping pattern. In the card-sorting study in phase 2, this grouping pattern was also agreed by 84% of the subjects.

The label “Route Plan” is selected for this group to stay consistent with document MSC.1/Circ.1609 (IMO, 2019).

4.13. Alerts

Replies from all subjects involved in the validation study in phase 3 indicate that there should always be a separated area on the display where all alerts associated with a system are displayed. This result reconfirms the findings on the card sorting study. At the same time, feedback from research subjects also indicate that a mechanism for quickly tracing an alert to the source that triggers the alert will allow users to quickly understand the messages and react more effectively.

5. Discussion

Before being implemented, the results presented in section 4 must be considered in terms of reliability and applicability. This section will discuss the methods used in terms of validity and reliability, as well as factors to consider when applying results of this research project.

5.1. Methodological Discussion

As discussed in section 3, this study consists of three phases, each with different methods. The methods used in each phase will be discussed in the following sections

5.1.1. The three sources of data in phase 1

The first phase involves establishing the general picture on the use of different functions on standard shipboard navigation systems. The authors combined existing cognitive analyse of navigation tasks with results of a survey of the frequency of use of each function on a standard INS and subsequently compared these data with performance standards of Radar, ECDIS and INS. As discussed in section 3, each of these three data sources has strengths and limitations, and by combining the three sources together, the authors minimised the weaknesses of each individual source to create the most reliable overview of the way seafarers operate navigation systems in practice.

The second phase involves a study employing card-sorting method which resulted in an initial pattern to group together 49 data/control functions on navigational displays that are most essential for safe operation of any vessel. The quality of this "initial grouping pattern" depends on the validity and reliability of the card-sorting method used.

5.1.2. Card-sorting Validity

Considering construct validity, the validity of card sorting as a method relies on the extent to which the way people cognitive categorise information is connected to their performance when working with interactive systems. Although card sorting has been widely used in developing information architectures, there are few studies that verify the connection between card sorting and improved system usability in a manner that can be scientifically evaluated.

One of the earlier studies in this topic was the study of internal structure of categories by Rosch and Mervis (1975). The authors conducted experiments using a set of artificially constructed strings of letters and digits. These strings were purposely constructed to form families (groups of strings that share common letters and/or digits). The level of family resemblance (the number of common attributes that strings of the same family share with each other) differs between families. Research participants learnt the strings and subsequently performed category recognition tests by identifying categories for certain strings. Results of the experiments showed that family resemblance and the lack of overlapping attributes with contrasting string families were correlated with ease of learning and user performance in identifying items after learning. Accordingly, classifying contents into groups with exclusive attributes can make it easier for users to memorise content structure and locate relevant items more accurately.

There are also studies that specifically evaluate the value of card sorting in improving usability of existing information structures. One of such studies is the redesign of indexes for the University of Arizona Library by a team of librarians (Dickstein and Mills, 2000). At the time of the redesign attempt, the indexes page, which were organised alphabetically, had already been criticised for lack of usability. The librarian team decided to group the indexes in subjects to make it easier for users to locate relevant items. To such end, the team conducted an open card-sorting study using a set of eighty-two cards. Results of the card-sorting experiment were a large number of index groups, which did not match the expectation of the librarian team. As a consequence, the team discarded those results and developed the index groups based on their perception of academic subjects. After several months, however, many library users complained the organisation and terminologies used on the indexes page to be confusing. The librarian team subsequently restructured the indexes page using results from the card-sorting experiment. The revised page allowed users to locate information more easily. This study is an example of designers and users having different mental models and the potential usability issues when designers ignore users' mental models (Dickstein and Mills, 2000).

Card sorting was also used to revise the structure for the Google AdWords Help Centre. Results of these card sorting exercises were developed into mock-up webpages and tests were conducted to compare user performance between the old webpage and the revised one. The experiment results showed that users performed tasks significantly faster with the revised Google AdWords Help Centre (Nakhimovsky, Schusteritsch and Rodden, 2006).

Besides traditional card sorting methods, a varied form called Modified-Delphi Card Sorting was employed in the redesign of the library website for National Taiwan Normal University. Following this method, a grouping pattern for contents of the library website was developed by a research participant. This "initial grouping pattern" was then reviewed and modified by eight other participants, one after another. Subsequently, another twenty subjects took part in findability testing for the pattern. Results of the findability tests indicated that the Modified-Delphi Card Sorting method led to improved findability for the website contents (Shieh and Wu, 2010).

In summary, there have been studies investigating the validity of card-sorting and their results indicate that grouping content in a logical manner makes it easy for users to find and access information, and card-sorting helps developing such logical grouping patterns.

5.1.3. Card-sorting reliability

There are different types of card-sorting methods, and the reliability may differ between them. However, since this study employed open card-sorting, it is only important to consider the reliability of open card sorting. To this end, Katsanos et al. (2019) conducted a study comparing data from six open card-sorting experiments involving 140 participants. These six experiments were divided into two sets of three. The first set of three were completed by eighty-two participants, using the same set of cards, and the number of participants for each experiment ranged from 16 to 34. The second set of three were completed by fifty-eight participants, using the same set of cards, and with a similar number of participants per experiment as the first set. All six experiments concerned general topics and did not require domain-specific knowledge. Correlation tests using Spearman's correlation and Mantel tests on distance matrices for studies of the same set found significant correlations in all cases. These results indicate that similar grouping patterns were produced by similar profile participants performing open card-sort exercises for the same content. Comparisons of dendrograms produced from the six card sorting experiments found high similarity in first-level categories (90.9%-95.3% for the first three experiments and 92.9%-96.5% for the second set). These results showed that different card sorting of the same content produced highly similar dendrograms in terms of first-level categories. Although there are limitations in terms of scope (only six card sorting experiments were considered) and the lack of consideration of qualitative data such as category labels, the study by Katsanos et al. (2019) provides support for the cross-study reliability of card sorting.

In summary, there are both academic studies and industrial applications to demonstrate the validity and reliability of the card-sorting method as a suitable tool for developing effective information architecture.

5.1.4. The validation study in phase 3

The validation study in phase 3 was conducted to simulate the way users search for information on navigational displays. There are, however, three issues with the way this phase was conducted.

Firstly, the research subjects were not shown complete screens but rather several fragments of Radar and ECDIS displays mixed together. In a real-life scenario, a subject would interact with a complete screen and would be given cues through the use of colours, the screen layout, and other contextual information, all of which could not be replicated in the study. Consequently, the method used in phase 3 lack ecological validity. However, by showing only fragments instead of complete Radar and ECDIS displays, the study avoided the possibility that research subjects could be biased toward the interfaces they are most familiar with or had used most recently.

Secondly, there is an issue with the number of research subjects. There were 49 pieces of data/control functions in the *initial grouping pattern*, and each research subject only answered seven questions concerning seven functions. As a result, it required seven research subjects for one complete evaluation of all 49 functions. With 35 subjects participated, it resulted in only five complete evaluations of the whole grouping pattern. In other words, each of the 49 pieces of data in the *initial grouping pattern* was evaluated by five research subjects.

The number of participants needed for a reliable usability study depends on several factors such as type and purposes of the study or characteristics of the user population. In this case, the aim is to identify issues with the *initial grouping pattern* resulted from the card-sorting study in phase 2, which fits the description of formative tests (Scholtz, 2000). With formative tests, Nielsen and Landauer (1993) reviewed 11 studies and suggested a number of 15 participants divided in three iterations of testing and redesigning. When applied to this study, since it required seven research subjects for one complete test, the total number of required research subjects would be 115, divided in three rounds of 35 subjects for each. However, due to logistical issues associated with the Covid-19 pandemic, it was not possible to achieve such number of research subjects. Consequently, only a third of the desired number of research subjects were recruited. Additionally, while the subjects were randomly selected, they were selected among the researchers' professional networks, which posed a potential issue with sampling bias. Considering all these factors, there is a potential reliability issue with the results of phase 3.

The third issue is with the data analysis method, especially with functions/information that received diverse opinions from research subjects. As discussed in section 3.3, if there was no *selected group* agreed by at least 80% of the subjects, the researchers would have to decide the *logical group* themselves after considering the subjects' answers, results of the card-sorting study in phase 2, and general usability principles. All three researchers have backgrounds in seafaring and maritime human factors. This procedure meant that there was a degree of subjectivity involved. The researchers did attempt to minimise personal biases by discussing results of the analyses together to reach a group consensus. Still, it was not possible to eliminate subjectivity entirely.

5.2. Applicability consideration

The *revised grouping pattern* resulted after phase 3 can be used to develop information architecture for Radar and ECDIS systems or their equivalent modules on an INS. However, given the limitations discussed in section 5.1, there are several factors to consider when applying the results of this study.

Firstly, the study is not comprehensive, in the sense that it does not consider the whole range of functionalities available on a standard Radar and ECDIS or their respective equivalent modules on an INS. The *revised grouping pattern* only contains 48 functions, arranged in thirteen (13) groups. When applied to an actual system, it is necessary to consider for the functions not included in this study. It is possible for future research to expand and include more functions to this grouping pattern.

Secondly, this study does not involve a formal usability tests where users' performance is quantitatively measured. As a result, any attempt to apply results of this study should include formal usability tests using high-fidelity prototypes and, ideally, with a comparison to an existing design.

Finally, the results of this study do not contradict any existing industry standards. Rather, these results complement and can be applied in conjunction with existing standards.

6. Conclusion

This article documents the backgrounds, methods, and results of a study consisting of three phases aiming to develop a logical pattern to group contents on the displays of Radar and ECDIS and their equivalent modules of an INS. The aim of such a grouping pattern is to allow seafarers to access essential information with minimal cognitive effort.

Phase 1 of the study involves establishing an overview of how seafarers use each function of bridge system when engaging in navigation duties. To this end, the researchers gather data from three source, namely cognitive analyses of navigation tasks, performance standards of navigation systems, and a survey on the frequency of use for each function of a standard INS.

Phase 2 of the study involves selecting, based on results of phase 1, 49 functions of Radar and ECDIS that are essential for safe navigation and conducting a card-sorting study involving 63 seafarers to develop an *initial grouping pattern* to arrange these 49 functions into twelve (12) groups.

Phase 3 of the study involves conducting a validation study with 35 seafarers to see whether the *initial grouping pattern* developed in the end of phase 2 corresponds with the mental model of seafarers when processing information available on navigation displays.

In the end, the *revised grouping pattern* contains 48 functions organised into thirteen (13) groups. One function was removed from the study as it was found to be incompatible with the rest. The resulted thirteen groups are presented in table 3 below.

No.	Group	Contents
1	Universal Presentation Settings (Fundamental)	Display mode indication (for MFD only)
2	*Should be placed near group "Universal Presentation Settings (Operational Display Area)"*	Screen brilliance level
3	Universal Presentation Settings (Operational)	Range scale/ Chart scale
4	*Should be placed near group "Universal Presentation Settings (Fundamental)"*	Range Ring scale
5		True Motion reset
6		Centred/Off-centred display
7		Orientation mode (NU/HU/CU)

8		Motion mode (TM/RM)
9		Stabilisation Mode & Stabilisation Source
10	Radar Display Settings	Radar system operational status (Standby/Transmit)
11	*Should be placed near group "Universal Presentation Settings (Operational Display Area)"*	Status (auto/manual) and level of Gain and Anti-clutter Control functions)
12	Chart Display Settings	Chart Display mode (Display Base/ Standard Display/ All)
13	*Should be placed near group "Universal Presentation Settings (Operational Display Area)"*	Chart Layer configuration (add or remove chart layers)
14	Chart Safety Settings	Anti-grounding zone (Look-ahead) settings
15		Safety contour settings
16		Safety depth settings
17		UKC
18	Target Settings	Target Trail Time and Mode indication
19		Target Vector Time and Mode indication
20	AIS settings	AIS processing status (On/OFF)
21		Status of filter for AIS targets together with filtering criteria (e.g., Range, CPA/TCPA, etc.)
22	Own-ship data	Own-ship HDG
23		Own-ship COG/CTW
24		Own-ship Rate of Turn
25		Own-ship SOG/STW
26		The source of own-ship's speed
27		Own-ship LAT/LON
28	Target Primary Data	Source of Target Primary Data (TT/AIS)
29		Target Range
30	*Placed next to Target Secondary Data*	Target Bearing
31		Target CPA
32		Target TCPA
33		Target Course
34		Target Speed
35	Secondary Target Data	Target Identification
36		Target Heading

37	*Placed next to Target Primary Data*	Target Rate of Turn
38		Target Navigational Status
39		Target LAT/LON
40	Tools	EBL readouts
41		Bearing Reference Indication (True/Relative Bearing)
42		VRM readouts
43		Cursor readouts
44		Line of Position (LOP) control
45	Route Plan	Route plan management
46		Way-point management
47		Route validation (checking the route against hazards)
48	Alerts	Alert status and associated information

Table 3. The *revised grouping pattern*

The results of this study do not contradict but rather complement existing industry standards and can be applied in developing graphical user interfaces for future systems. However, the study does not involve all available functions of navigation systems and there were no formal usability tests where users' performance could be quantitatively measured. These two factors must be considered when applying this grouping pattern. Also, it is possible for future research to build upon the results of this study and develop a more comprehensive information architecture for shipboard navigation systems.

ACKNOWLEDGEMENTS

The researchers would like to show our gratitude to all seafarers and maritime professionals who took part in the study. Our special thanks to the Nautical Institute, Optimal Workshop, and Capt. Sriram Rajagopal of Anglo Eastern.

ETHICAL STANDARDS

This project was conducted following standards set out by the Norwegian National Committee for Research Ethics in the Social Sciences and the Humanities. All personal data were anonymised and managed under project number 60814, managed by the Norwegian Centre for Research Data.

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Annex 1

Table 4 below contains contents of the 49 cards used in the card sorting study in phase 2 of this research

No.	Data or Control function
1	Display mode (ECDIS, Radar,Conning display, etc.) - for Multi-function Displays only
2	Source of Target data (TT/AIS)
3	Target Range
4	Target Bearing
5	Target CPA
6	Target TCPA
7	Target Course
8	Target Speed
9	Target Identification (from AIS data)
10	Target Navigational Status (from AIS data)
11	Target Position (from AIS data)
12	Target Rate of Turn (from AIS data)
13	Target Heading (from AIS data)
14	AIS processing status (ON/OFF)
15	Status of filter for AIS targets together with filtering criteria (e.g. Range, CPA/TCPA, etc.)
16	Alarm/Warning status and criteria
17	Chart scale/ Range scale
18	Range Rings scale
19	Orientation Mode (NU/HU/CU)
20	Motion (TM/RM) mode
21	True Motion reset
22	Centered/ Off-centered display
23	The stabilization mode and stabilization source
24	The source of own-ships' speed
25	Presentation settings for target vectors (e.g.: True/Relative vector, vector time, and vector stabilisation)
26	Target Trail Time and Mode Indication
27	Status (automatic/manual) and level for gain and all anti-clutter control functions
28	VRM readout
29	Bearing Reference Indication (True or Relative Bearing)

30	EBL readout
31	Screen brilliance level
32	System operational status (Standby/Run – mandatory for Radar only)
33	Cursor Readout (Range and Bearing, LAT/LON)
34	Chart Display mode (Display Base/ Standard Display/ All other information)
35	Chat Layer configurations (add or remove chart layers)
36	Safety contour settings
37	Safety depth settings
38	Way-point management (view/ add/ delete/ modify)
39	Route plan management (select active route/ alternative routes, store and load/ import and export routes , etc.)
40	Look-ahead (also called Own-ship check or Safety Frame – depends on ECDIS manufacturer) settings
41	Time-labels (displayed along the ship's track) settings
42	Lines of position (LOP) control
43	Route validation/Route check control (Check the route plan against hazards, areas with restricted manoeuvrability, and meteorological information, etc.)
44	Own-ship LAT/LON
45	Own-ship HDG
46	Own-ship COG/CTW
47	Own-ship SOG/STW
48	Own-ship ROT
49	UKC

Table 4. Contents of the 49 cards used in the card sorting study forming phase 2 of this research

Annex 4 – Paper IV

Title Page

Title

Developing human factors engineering guidelines for marine electronics – the case of S-mode

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Abstract

Human factors issues with navigation equipment have been identified as a challenge to safe and efficient maritime operations. A reason behind the issues is the lack of guidance from regulatory agencies, particularly regarding interface design. The International Maritime Organisation [IMO] has taken measures to address the situation, an example of which is the development of Circular MSC.1/Circ.1609 Guidelines for the Standardisation of User Interface Design for Navigation Equipment. This article presents a case study on the development of MSC.1/Circ.1609. An in-depth analysis was conducted using multiple sources of data to identify influential factors behind key events and provide recommendations for similar future initiatives. The study finds the development of MSC.1/Circ.1609 to be affected by the politics of decision-making at the IMO, the difficulties associated with developing implementable technical regulations, and the rigid nature of IMO working procedures. The findings suggest that successful human factors regulations should address the requirements of both end-users and implementors, which are equipment manufacturers in this case. This study also identifies characteristics of IMO working principles that should be considered to improve the application of human factors in the maritime field.

Keywords

human factors, IMO, policy-making, user-centred design

Statements and Declarations

The authors declare that there are no competing financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

1. Introduction

In 2007, the Nautical Institute [NI], in collaboration with the International Federation of Shipmasters' Associations [IFSMA], submitted a paper to the International Maritime Organisation's [IMO] Sub-committee on Safety of Navigation [NAV] proposing a concept called "S-mode" for shipboard navigation systems. The idea was that all navigation systems should have a standardised interface, which can be activated by a single operator action. This standardised interface would exist alongside the interface customised by each manufacturer. S-mode was proposed as a solution to the increased complexity and diversity in interface design for navigation equipment, which was a concern to safety of navigation at the time, while still allowing room for manufacturers to innovate (IMO, 2007a). The S-mode concept was subsequently adopted as a part of IMO's e-Navigation initiative, which regulates the introduction and implementation of new information technology in shipping.

S-mode was developed by a correspondence group formed by volunteered IMO member states and affiliated organisations. The final result was published in 2019 in the form of document MSC.1/Circ.1609 *Guidelines for the Standardisation of User Interface Design of Navigation Equipment* by the Maritime Safety Committee [MSC] (IMO, 2019b). Document MSC.1/Circ.1609 shares little commonality with the original S-mode concept. There is no standardised interface for any navigation equipment. Instead, MSC.1/Circ.1609 introduces human factors principles to be considered when designing navigation equipment, together with four standardised features of the user interfaces: standard icons and terminologies for essential nautical concepts, the arrangement of key information/control functions into groups, functions that must be accessible by either single or simple operator actions, and default configurations for Electronic Chart Display and Information System [ECDIS] and Radar as well as their equivalent modules on Integrated Navigation System [INS]. Despite the label "Guidelines", there are clauses in MSC.1/Circ.1609 making these standard features mandatory for navigation equipment manufactured from January 1, 2024.

The development of S-mode spanned a long period of time and was an industry-wide effort to improve usability[1] of shipboard navigation systems through regulatory incentive. It can be considered a joint effort with the participation of several IMO member states and non-governmental organisations [NGO]. An initiative like S-mode is uncommon in the maritime field and the development of S-mode can serve as an example to facilitate similar future IMO initiatives.

This article presents a study conducted to analyse the development of S-mode with the direct objective of identifying contextual factors that supported or impeded the development process. The long-term objective of this study is to, through the case of S-mode, provide recommendations to facilitate similar IMO projects in the future. The goal of this study is to support human factors application in the maritime field through a regulatory incentive.

Since circular MSC.1/Circ.1609 originates from the S-mode concept, the document is still unofficially referred to as the "S-mode guidelines". For the convenience of readers, the two terms "S-mode" and "S-mode guidelines" will be used to refer to circular MSC.1/Circ.1609 for the rest of this article.

2. Backgrounds

The maritime industry has seen, in recent years, an increased application of information technology to improve safety and efficiency. On the bridge of a ship, a visible outcome of this change is the introduction of computer-based electronic systems, for example the gradual replacement of paper charts by ECDIS in the 2010s.

While these systems can bring benefits to improve safety and efficiency of navigation, they also bring new challenges. The design of ships and shipboard systems directly affects the bridge team's performance and, consequently, outcomes of shipboard operations. While most operations are successful, accidents do occur, and improper design of shipboard systems has been identified among contributing factors in several accidents (MAIB, 2014, 2017; NTSB, 2014). Problems arise when the designers/developers focus on technical and economic aspects, while not giving sufficient consideration to the abilities and limitations of the intended users. Consequently, many systems are technically functional but difficult to operate, increasing the probability of users making erroneous actions.

[1] Usability refers to the extent to which a product can be used by the intended users, in the intended working environment, to achieve the intended goals with effectiveness, efficiency, and satisfaction ISO. (2010). *9241-210:2010 - Ergonomics of human system interaction - Part 210: Human-centred design for interactive systems*. International Organization for Standardisation.

A recent study published by the MAIB and DMAIB (2021) on the use of ECDIS finds similar issues already identified many years prior, such as complex interfaces and improper alert management (IMO, 2003). These findings suggest that the implementation of electronic navigation systems has not yet reached maturity. There are persisting usability issues and human factors is still not properly considered when designing navigation equipment, especially when it comes to user interfaces.

Design issues with shipboard systems can be mitigated by giving due consideration to human factors through means such as consulting specialists or involving users in the design process. An example of this practice is the design and construction of the Ro-Ro vessel Harvest Leader, which is owned and operated by NYK Line. The contracted naval architects have taken measures to ensure the design of the ship not only meets her operational requirements but also have features that make it easy for the crew to live and work onboard. Specifically, the naval architects consulted the crews to learn how they work and their experience from similar vessels and applied such knowledge in the final design (Bialystocki, 2016). Other examples include the construction of Tamar-class lifeboats for the Royal National Lifeboat Institution (Chaplin & Nurser, 2007), or the Platinum integrated bridge and engine control room systems by SAM Electronics (now Wartsila) (Wartsila, 2019). At a higher level, the IMO has taken initiatives to encourage involved stakeholders to consider human factors when introducing new technology, such as the issue of document MSC/Circ.1091 - *Issues to be considered when introducing new technology on board ship* (IMO, 2003) or more recent initiatives such as e-Navigation. Nevertheless, these cases do not reflect common practice and there is still no systematic industry-wide approach for human factors consideration in the maritime field. Marine technology is still being developed mainly from technical and economical viewpoints (Petersen, 2010).

There are many reasons behind this current status of maritime human factors. One reason is that human factors itself is a new area of knowledge in the maritime domain, as seen through the number and year of publication of both academic publications and industry documents on this topic (Schröder-Hinrichs et al., 2013). Among the published guidelines and instructions for human factors consideration in the design of bridge and bridge equipment, the dominant focus is on physical infrastructure such as dimensions and equipment layout, while there are only limited number of documents on user interface design, both hardware and software (Mallam & Nordby, 2018).

Within this context, the development of S-mode was an attempt by the IMO to improve the usability of shipboard systems by applying human factors design principles. The four standard interface features forming the core of the S-mode guidelines were developed following a user-centred approach as recommended in ISO 9241:2010 (ISO, 2010), taking due consideration to the requirements of seafarers who are users of navigation equipment. The work conducted to develop S-mode is characterised by two aspects. Firstly, S-mode was an official IMO project, conducted by an official IMO correspondence group. As a result, there are certain political and bureaucratic aspects of IMO working procedures that shaped the development of S-mode. For instance, the conflicts of interest between involving parties, the role politics plays on decision-making at the IMO, and the compromises made by each participant to reach agreements, are among the important factors that shaped the development of S-mode. At the same time, S-mode can be considered a design project with the interfaces of various navigation equipment as design objects and user-centred design as the overall design principle. From this angle, there are technical challenges associated with the conduct of a joint design project at the IMO level that should be considered.

To provide a full context to this study, it is important to state that the first and second authors were members of the group responsible for developing S-mode and, thus, have access to data not available to the public. The first author was only involved with S-mode from 2017 until the approval of the S-mode guidelines in 2019. The second author, however, was involved with S-mode since the emergence of the concept in early 2000s. The third author, meanwhile, was not involved with S-mode.

It should be noted that the group responsible for developing S-mode was an official correspondence group established by the IMO under the title “S-mode correspondence group”. For the rest of this article, the term “S-mode correspondence group” will be used to refer to the group of delegates from several IMO member states and organisations that developed the S-mode guidelines.

3. Research design

The choice of research methodology is influenced by the research context and guided by the research aim(s), epistemological concerns, and norms of practice of relevant work in the research area (Buchanan & Bryman, 2007). When selecting a suitable methodology for this study, the most important factor to be considered was the research objective of understanding contextual factors that shaped the development of S-mode. To complete this objective, the research must answer two questions:

1. What were the key events that occurred during the development of S-mode?
2. What were the factors that influenced the behaviours of the involving parties and affected the outcomes of key events during the development of S-mode?

In question 1, the term "key event" is used to refer to any event or decision that led to the establishment of or changes to at least one of the following: the status of S-mode as an official IMO project, the scope of S-mode, and the content of S-mode. To answer this question, the authors must first reconstruct a detailed description of all activities associated with the development of S-mode as accurate as possible, which would require using multiple sources of data.

To answer the second question, it is required that the authors have a clear understanding of the context in which the development of S-mode was carried out and, more importantly, how such context was viewed by the involving stakeholders. Understanding of context is a prerequisite to see an action through the perspective(s) of the actor(s) and, subsequently, to provide explanations to such action (Mason, 2002). To this end, the authors require a method capable of capturing the different perspectives of the stakeholders who took part in the development of S-mode. The inclusion of stakeholders' multiple perspectives is also important to achieve the desired level of comprehensiveness and improve the validity of the findings.

3.1. Joint activity as the conceptual framework

In this study, the interaction and collaboration between IMO members and organisations in the development of the S-mode guidelines is viewed through the concept of joint activity introduced by Clark (1996).

The concept of joint activity was defined by Clark (1996) as any activity with more than one participant, where the participants coordinate to reach common goals and their actions are interdependent. In his work, Clark (1996) uses the concept to explain how people use language in communication. However, Clark (1996) based his definition of joint activity on Levinson (1979)'s notion of "activity" as any culturally recognised activity whether or not any use of languages is involved. Thus, the concept of joint activity can be used to describe an activity in any domain, as long as such activity satisfies the criteria to be considered a "joint" one.

The first prerequisite of a joint activity is that the involved parties agree to work together to achieve certain common goals. It should be noted that having common goals does not mean all participants in a joint activity follow the same agenda. More often, each party has individual goals, which can be made public or kept private. In some cases, individual goals of each party can conflict with each other. A joint activity emerges when involving parties commit to align their individual interests to a certain degree to form common goals (Klein et al., 2005). In the case of S-mode, the involving stakeholders did have a common goal of developing the S-mode guidelines while, at the same time, have individual goals of defending the interests of the organisation they represented, be it an IMO member state or a NGOs.

Another prerequisite of joint activity is the interdependence between the involved parties. Clark (1996) argues that, in a joint activity, the actions of one party must have certain impacts on the actions of other parties and vice versa. If the actions of parties to an activity have no influence on each other, such an activity is not considered a joint activity but a parallel activity. As an IMO initiative, the work to develop S-mode has, since the beginning, been a series of negotiations and agreements between IMO member states and organisations. There were always arguments and counter arguments, and actions of one stakeholder significantly affected actions of others, even before the existence of a common goal.

Considering both criteria, it can be argued that the development of the S-mode guidelines fits the criteria of a joint activity, and the model of joint activity can be used to explain the interaction between the involved stakeholders.

3.2. Case study as the overall methodology

Case study is a qualitative methodology suitable for providing a holistic, in-depth understanding of social phenomena in the natural context and is capable of bringing out details from the multiple viewpoints of the involving stakeholders (Johansson, 2007; Tellis, 1997; Yin, 2009). Case study methodologies have been employed in studying similar topics, such as the adoption of STCW 95 (Dirks, 2004) or the development of the Convention on Long-range Transboundary Air Pollution (Lidskog & Sundqvist, 2002).

Considering the research objective, the characteristics of case study methodology, and the application of case study in previous relevant studies, the decision was made to adopt case study as the overall methodology for this study, specifically following the instrumental framework.

In an instrumental case study, it is not the main priority to understand the case itself but rather, through an understanding of the case, providing insights into an external matter, which could be an issue that needs to be addressed or a theory requiring refinements (Stake, 1995). In other words, the case under study is of secondary interest and serves a supporting role, enabling the researchers to understand the external interest. To serve this supporting role, the selected case would be looked at in depth, with detailed analysis of the underlying contexts and involved activities. In this thesis, the case of interest is the development of the S-mode guidelines, with the underlying goal of explaining the lack of human factors consideration in designing bridge equipment through a regulatory viewpoint.

An important question to consider when conducting case studies is the choice between the single-case and multiple-case approach. Meyer (2001) suggests a multiple-case approach is more desirable to a single-case approach due to the advantage of enhanced external validity and reduced observer bias. The study of multiple cases, each with its own context, allows the researchers to analyse and compare across contexts and generalise theories. Flyvbjerg (2006), however, challenges this view and argues that an in-depth study of a single case can generate knowledge valid beyond the local context, especially when used for falsification testing. The authors support both views and believes a multiple-case approach should be followed if applicable while, at the same time, also acknowledges the contribution of single-case studies in generating and expanding scientific knowledge. This study employs a single-case approach as a pragmatic choice. Following a multiple-case approach requires access to data of multiple cases with comparable levels of detail, which was not available to the authors. On the other hand, authors have access to a large amount of data on the case of S-mode, resulted from their time being members of the S-mode correspondence group. As a result, a single-case approach was selected, and measures were taken to address the weaknesses of single-case approach. In specific, the study employed triangulation of data and investigators (Baxter & Jack, 2008).

Triangulation of data was achieved by using multiple data sources. This study was conducted in two consecutive steps of data collection and analysis. The first step aimed to analyse the development of S-mode through studying written records accessible to the author, including official records issued by the IMO and relevant organisations, email correspondences between members of the S-mode correspondence group, and the first author's personal record. Once this step was completed, the authors commenced the second step, which aimed to analyse the development of S-mode through the perspectives of the major stakeholders. The objective of this second step was to validate results of the first step and provide a more comprehensive account of the S-mode development process.

Triangulation of investigators was achieved by having multiple researchers involved in data analysis and interpretation. In this case, the first author conducted data analysis independently, but the results were subsequently discussed with the other co-authors to avoid biases and misinterpretations.

The following sections provide a detailed descriptions of the procedures for data collection and analysis in each step of this study.

3.3. Step 1 – Document analysis

The approach in this step was inspired by the qualitative historical analysis approach, which refers to the qualitative methodological approach for studying past events by investigating documents (Thies, 2002). This approach has been employed in studying policy-making process in international negotiations, an example of which is the study on IMO Sulphur regulations for ships by Svensson (2014).

The choice of historical documents is crucial in qualitative historical analysis. Thies (2002) categorises historical sources into primary and secondary sources. Primary sources are original materials produced on an event while secondary sources refer to documents written about an event subsequent to its occurrence. This study uses both primary and secondary sources in the form of:

1. Official documents including documents submitted to IMO negotiations, reports issued by various IMO organs, and supportive documents from 2007 to 2019
2. Material available to members of the S-mode correspondence group, including email conversations between members and relevant materials published by the group (reports, presentations, and magazine articles) between 2017 and 2019
3. Personal records of events related to the development of S-mode, kept by the first author during his time as a member of the S-mode correspondence group (2017-2019)

Of these three data sources, the first source generates the most amount of data as it covers the whole process of developing the S-mode guidelines since the first emergence of the concept to the final approval of the S-mode guideline. The archival procedure included reviewing documents from all sessions between 2007 and 2019 of various IMO organs including the Maritime Safety Committee [MSC], the Sub-committee on Safety of Navigation [NAV] (until 2013), the Sub-committee on standards of training and watchkeeping [STW], and the Sub-committee on Navigation, Communications and Search and Rescue [NCSR] (since 2014), as well as records of those events kept by delegates of IMO member states and organisations, particularly the Norwegian Maritime Authority [NMA] (Norwegian: *Sjøfartsdirektoratet*). In total, 90 documents were included as the first data source for this study. Appendix 1 contains a list of all documents included in the first data source.

Data from these three sources were entered into NVivo data analysis software and the authors conducted a thematic analysis on these data using a procedure similar to one used by Boyatzis (1998). In specific, the analysis followed the following steps:

- The authors first developed an initial coding scheme by scanning the second and third data sources repeatedly to identify "key events" which, as stated in the beginning of chapter 3, meant any event or decision that led to the establishment of or changes to at least one of the following: the status of S-mode as an official IMO project, the scope of S-mode, and the content of S-mode. Concluding this step, the authors developed an initial coding scheme that identified five key events that shaped the development of S-mode. For each of these five events, factors that affected the behaviours of the involving stakeholders were categorised into technical and non-technical factors. Category "technical factors" contains data associated with the technical aspect of S-mode as a design project. Category "non-technical factors" contains data not belonging to the first category
- The first author used the initial coding scheme to code the data from the first source – written records issued by the IMO and relevant organisations. Throughout this process, the initial coding scheme was modified several times as categories emerged, being discarded, or being merged together. This process was repeated until no modification was needed to the coding scheme. The coding scheme was subsequently jointly reviewed by all authors, and it was agreed that no further change was needed
- The final coding scheme contains five top categories, which represented five key events during the development of S-mode. These top categories are:
  - The emergence of the initial concept
  - Becoming a part of e-Navigation
  - Defining the scope of S-mode
  - Developing the contents of S-mode
  - Final approval

The result of this coding process helped identify five key events during the development of S-mode and the actions of each involving stakeholder during each event. This initial result was not considered fully reliable due to three reasons. Firstly, the development of S-mode spanned a long period with many events occurred. While being members of the S-mode correspondence group, none of the authors were fully involved in all events/discussions that occurred during the development of S-mode. Secondly, besides official events, there were unofficial events such as informal meetings and discussions, the records of which were not available to the authors. Still, many of those unofficial events influenced the outcome of S-mode. Finally, these initial results did not capture the perspectives of other stakeholders involved in S-mode. As a result, the authors commented the second step of this study, aiming to address these shortcomings.

3.4. Step 2 – Interviews with stakeholders

The second step of this study was commenced to complement results of the first step by collecting data from another source: the stakeholders who were involved in developing S-mode. To this end, the authors conducted interviews with major stakeholders.

To select the stakeholders to interview, the authors conducted a stakeholder analysis using a procedure adapted from the stakeholder matrix version 2 by Heidrich et al. (2009) The specific procedure was as follows:

- The authors listed all stakeholders involved in the development of S-mode using all three sources of data
- The authors ranked the stakeholders on two characteristics: technical and political contributions. Technical contribution refers to the work performed by a stakeholder, through technical expertise and resources, to

shape the contents of S-mode. Political contribution refers to the political and diplomatic work a stakeholder performed to influence IMO decisions related to S-mode

Following the analysis, interviews were conducted with major stakeholders (n = 4). The interviewees represented two IMO member states: Australia and Republic of Korea, and two Non-Governmental Organisations [NGO]: the Nautical Institute [NI] and the International Association of Marine Electronics Companies [CIRM].

Before the interviews, the authors shared with each interviewee the initial results of step 1, which identified five key events during the development of S-mode together with the actions of involving parties during each event and explained influential factors behind each event from a technical and non-technical aspect. By sharing these results, the interviewees were able to make necessary preparations, such as holding discussions within their own organisations, before joining the interviews.

The interviews were semi-structured. Using predetermined questions, the interviewees were first asked to review the initial results from step 1 of this study and give their own accounts of main events during the development of S-mode. Based on the interviewees' answers, there were follow-up questions aiming to identify factors affecting each of the key events/decisions during the development of S-mode.

The interviews with major stakeholders generated a fourth source of data. The interviews were transcribed and entered into NVivo data analysis software. This data set was collected to achieve two purposes. Firstly, it was used to as an additional source to validate the accuracy of the document analysis in step 1 of this study. To this end, the authors analysed the interview data using the same coding scheme from the document analysis. The authors did not identify any conflicting record between the document data in step 1 and the interview data in step 2 regarding the events that occurred during the development of S-mode.

The second purpose of the interview data was to explain the key events during the development of S-mode through the perspectives of major stakeholders. The interview data suggested that categorising factors affecting each key event during the development of S-mode into technical and non-technical categories, while valid, was an over-simplified approach. To address this issue, the authors expanded the coding scheme resulted from step 1 by analysing interview data without applying a theoretical preposition. This approach allowed the emerge of new patterns, which provide more insights into the events that shaped the development of S-mode.

In summary, the interviews with major stakeholders generated another source of data, which enriched the available data set. This fourth data source did not contradict any result obtained from the initial data. Rather, the data added a level of reflection of major stakeholders on events happened during the development of S-mode and provided further explanations as to why S-mode ended up as document MSC.1/Circ.1609.

3.5. Rigour

Methodological rigour was achieved by following established measures to improve validity and reliability for case studies (Denzin & Lincoln, 2018; Yin, 2009; Yin, 2013).

In specific, this study employs multiple data sources: official records by the IMO and other maritime organisations, email correspondence within the S-mode CG, the author's personal record, and interviews with four key stakeholders. These multiple sources of data allow the authors to approach the development of S-mode from multiple angles. The interviews with key stakeholders were semi-structured and special attention was given to conflicting perspectives between interviewees. The study could have been improved by interviewing more stakeholders to generate a more comprehensive data set. However, such an attempt was not practical, given the limited timeline and resource available for study.

Additionally, all three authors were involved in analysing data, which help minimise personal biases. The authors also sent summarises of the findings to the interviewed stakeholders and two other members of the S-mode correspondence group who were not involved in this study. This step further reduced potential biases and helped avoid misinterpretations.

Procedures for data collection and analysis are described in detail. Data from the first source are detailed in Appendix 1. Data from other sources including email conversations between members of the S-mode correspondence group and interviews of key stakeholders are made available for a small group of distinguished researchers. The questionnaires used for interviewing major stakeholders are included in Appendix 2. This arrangement allows easy replication of this study by other researchers.

4. Results

The results are presented in two parts. The first part answers the first research question by summarising the key events that occurred during the development of S-mode. The second part answers the second research question by discussing contextual factors affecting each of the identified key events.

4.1. The development of S-mode

In this section, the authors organise the presentation of findings following the chronological order of the five key events during the development of S-mode that were identified during our analysis.

4.1.1. The emergence of the first S-mode concept

Toward the late 1990s, the NI started observing an increased level of sophistication and complexity with navigation systems, particularly with the Radar. The Institute also, at the time, had a vision that the future of bridge equipment would be integrated navigation systems. Considering potential issues with future navigation equipment, the NI held a series of international conferences on Integrated Bridge Systems and Human Element in 2002 and 2003. The attendees represented several industry stakeholders including equipment manufacturers, seafarers, and researchers. Many interesting topics were discussed but there was one particular discussion where delegates raised concern that navigation equipment was getting too diverse in terms of user interfaces and functionalities. Delegates were also concerned that the training were focusing mainly on teaching seafarers to use different functions and controls rather than teaching them how to use the equipment to navigate safely and effectively. The delegates argued that a greater level of equipment standardisation was needed, which would facilitate training and familiarisation. The NI subsequently submitted a paper to the IMO summarising the issues raised during the conferences. The IMO acknowledged these issues in circular MSC/Circ.1091 (IMO, 2003), which serves as the official recommendations for member states to consider when introducing new technology on board.

When the concept of e-Navigation emerged in 2005, a part of e-Navigation involved improving the standardisation of bridge equipment (IMO, 2005), the NI recalled document MSC/Circ.1091 and started to work on finding a solution for this standardisation issue, in close collaboration with manufacturers of marine electronics through the International Association for Marine Electronics Companies [CIRM]. The manufacturers did not unreservedly support further standardisation efforts, believing that an increased level of standardisation would limit their ability to innovate and introduce new features. Such a limitation could force innovative manufacturers to cut back on their research and development [R&D] to be able to compete with manufacturers who produce low-cost systems with basic functionalities. The NI recognised the merit of this argument and came up with a solution: a separate standard interface, called "S-mode", would exist alongside the brand-specific interface developed by each manufacturer. The NI believed that such a stand-alone standard interface would bring improved standardisation while still leaving room for manufacturers to innovate.

The idea received supporting feedback from maritime professionals (Patraiko, 2007) so the NI collaborated with the International Federation of Shipmasters' Associations [IFSMA] to introduce this "S-mode" concept to the IMO in the 53rd session of the sub-committee on safety of navigation [NAV] in 2007 (IMO, 2007b). This was the first time S-mode was officially introduced to the IMO. The concept was negatively received by marine electronic companies. While many complex arguments were made against S-mode, one persistent motivation from manufacturers was that they wanted the freedom in designing their products to use innovative features as selling points. Considering the large number of manufacturers (as of October 2021, there were 106[2] members of CIRM) in such a small market as marine electronics, innovation and unique selling points are important to secure market share. Additionally, a standard interface could potentially lock in users, making it difficult for any subsequent change/update. On the other hand, there were arguments supporting S-mode, referring to published studies and particularly document MSC/Circ.1091 (IMO, 2003), which recognised the lack of standardisation in equipment design as a real issue. The discussions were inconclusive, and S-mode was set aside for future consideration.

[2] It should be noted that although not all 106 CIRM members are manufacturers of marine electronics, a majority of them are. There are also government agencies such as the UK Hydrographic Office or the US Coast Guard among the members.

4.1.2. Becoming a part of e-Navigation

During the period 2008-2010, the IMO did not further consider S-mode as the Organisation was focusing on developing the e-Navigation Strategy Implementation Plan [SIP]. Nevertheless, results of e-Navigation work such as surveys conducted by Germany (IMO, 2009a), Canada (IMO, 2009b), and Republic of Korea (IMO, 2010b) raised support for S-mode as a potential e-Navigation solution.

The work on e-Navigation and, in expansion, S-mode, until 2010 was coordinated by the United Kingdom. Progress during this period was limited due to internal political tensions and limited resources assigned by the UK government for the task. Norway replaced the UK as the coordinator for e-Navigation in 2010 and took a different approach. Norway was willing to invest more in e-Navigation, both human and capital resources. This can stem from the tradition of Norway being a country welcoming new technology and innovation. It was Norway's diplomatic efforts that got involved stakeholders to work together and pushed the progress on e-Navigation tasks.

The development of e-Navigation SIP reached the final stage in 2013 and, by that time, S-mode had gained a firmer position as an e-Navigation solution under the label "Standardised mode(s) for navigation equipment" (IMO, 2013, p. 24). It was envisioned that S-mode would incorporate default display configurations for ECDIS and Radar and standardised interface modes for predefined operational areas including open sea, coastal or restricted waters. Such standardised interface modes would be accessible by a simple operator action and exist alongside a customised interface developed by each manufacturer. Still, it was not clear what specifications these standardised interface modes should have and S-mode remained an abstract concept at this point.

A critical moment in the development of S-mode took place during the 1st session of the IMO sub-committee on navigation, communication and search and rescue [NCSR] in 2014. The CIRM submitted a proposal to remove S-mode from the e-Navigation SIP, pointing out several issues with the concept (IMO, 2014b). Firstly, the implementation of S-mode, as the concept was currently described, would remove the incentive for manufacturers to produce their own interfaces as there would be no need for type-specific training and seafarers would have little interest in using manufacturer-customised interfaces instead of S-mode. Secondly, S-mode would make it difficult for manufacturers to update their systems to keep up with technological advancement or in case user requirements changed. Additionally, S-mode would make it difficult to cater to specific needs of different markets or maritime sectors. Finally, there had already been other initiatives that could also bring improved usability to navigation systems without the need for a fully standardised interface. Consequently, CIRM expressed concerns that S-mode would overlap with existing initiatives, introduce new challenges, and delay the implementation of e-Navigation.

CIRM's proposal received support from many delegates, specifically:

- International Maritime Pilots' Association [IMPA] – Pilot users had given the topic of S-mode deep consideration based on experience of using different equipment and modes and supported CIRM's proposal. The IMPA believed that alternative solutions such as the introduction of save/recall functionalities would be more pragmatic and bring real benefits
- The US commented that they did not believe S-mode to be a suitable e-Navigation solution but, at the same time, did not disregard S-mode completely
- Sweden, Japan, the Netherland, and France also supported CIRM's proposal

However, there were strong opinions against CIRM's proposal, specifically:

- Australia agreed with some of CIRM's arguments but believed that there was insufficient evidence to evaluate how much alternative measures could address the issues with lack of equipment standardisation. Until it could be proven otherwise, Australia supported retaining S-mode in the e-Navigation SIP
- Denmark supported the S-mode concept, believing that it would address user needs, and did not believe that S-mode would impact manufacturers' ability to innovate. Denmark commented that the industry had reached a level of diversity where a solution like S-mode would be necessary
- Norway supported Denmark's comment and also voted to retain S-mode in the SIP. Norway further commented that S-mode received a lot of support from delegates during the 42nd session of IMO sub-committee on standards of training and watchkeeping [STW] and, therefore, believed that there was a need for a concept like S-mode

- International Association of Independent Tanker Owners [INTERTANKO] believed S-mode to be critical for safety and, therefore, did not support removing S-mode from the e-Navigation SIP
- The NI argued that S-mode would address user needs as currently users had to adapt to various systems made by different manufacturers. The NI also stated that studies by IMO member states had found S-mode to be a suitable e-Navigation solution and they did not consider alternative measures mentioned in CIRM's proposal to be adequate for addressing the identified user needs
- Singapore, the Bahamas, the Marshall Islands, Panama, Kiribati, the Republic of Korea, Nigeria, and Poland aligned with other member states in support of retaining S-mode in the e-Navigation agenda

Concluding NCSR 1, CIRM's proposal was not approved, and S-mode remained a part of the e-Navigation SIP. The strong support from a large number of IMO member states assured S-mode a firm position as an e-Navigation solution. The status of S-mode as an e-Navigation solution was officialised after the MSC approved the e-Navigation SIP in November 2014 (IMO, 2014a).

4.1.3. Defining a scope

In 2015, an informal correspondence group on S-mode was formed under the coordination of Australia. Members of the group worked on two tasks simultaneously: organising workshops and discussions to agree on a scope of S-mode and conducting user studies to identify user needs regarding the standardisation of navigation equipment.

An important workshop was held in South Korea in 2015. During the event, the International Electrotechnical Commission [IEC] and CIRM proposed that S-mode should not be a fully-standardised separate display mode but rather the standardisation of certain features of the interfaces such as indicators, presentation of essential information, and common terminologies (IMO, 2015). This proposal was not adopted as the official S-mode agenda but involving parties agreed that a fully standardised interface would no longer be prioritised, should other solutions be able to bring similar usability benefits (IMO, 2016). This 2015 workshop was also the time when CIRM started participating more actively in the development of S-mode to ensure their inputs would be reflected in the final outcome as it would be the manufacturers who must subsequently implement S-mode.

Further work during 2015-2016 saw S-mode gradually depart from the initial concept of fully-standardised interface mode(s) for navigation systems. As of 2016, it was envisioned that S-mode would become a set of standard guidelines for designing navigation equipment, which would also standardise certain features of the interfaces (IMO, 2016). Still, the S-mode correspondence group could not agree on the exact scope of S-mode, including questions such as to which equipment S-mode would be applied, which features of the interfaces would be standardised, and how such standard features would be developed.

The CIRM had several concerns with S-mode at the stage of 2016. They felt that some members of the S-mode correspondence group were aiming for S-mode to be prescriptive standards. The CIRM reaffirmed their stand that they would not support a rigid and comprehensive standardisation and urged other members to aim for a "middle ground". The CIRM also believed that S-mode, in the current form, was too abstract and could not be implemented. Another issue was that S-mode was intended to be an IMO guideline, which is the weakest IMO regulatory instrument and would not give manufacturers a regulatory incentive for implementation. Considering these factors, the CIRM formed their own S-mode technical group to develop an alternative S-mode solution. They presented their results during the e-Navigation underway Asia-Pacific 2017 conference in South Korea.

This alternative S-mode concept, as proposed by CIRM, would standardise four features on the displays: icons and terminologies, the grouping of key functions and controls, quickly accessible functions, and default system settings. These features could be applied to a wide range of bridge equipment.

CIRM's alternative S-mode quickly gained support from most members of the S-mode correspondence group as this was, by far, the only solution with a clear development pathway. Also, the goal of S-mode was never to introduce a fully standardised interface but rather to find a solution to improve the standardisation of bridge equipment, which this alternative S-mode concept did support. CIRM's proposal was subsequently incorporated into to the official scope of S-mode, approved by the NCSR in 2018 (IMO, 2018a).

The finalised scope of S-mode contained a set of human factors guidelines in the design navigation systems and four standard features of navigation displays as proposed by the CIRM. It was expected that S-mode would become an IMO circular. Since the scope of S-mode had been determined, the main work of the S-mode correspondence group during 2018-2019 was to develop and finalise contents of the S-mode guidelines.

4.1.4. Developing contents of the S-mode guidelines

During NCSR 5 in 2018, members of the S-mode correspondence group met at the IMO headquarters and jointly drafted the first version of the S-mode guidelines, which contained two parts. The first part contained human factors principles for designing navigation systems and was drafted based on previous work by human factors specialists among the group members. The second part contained four standard features of the displays for navigation systems and was developed by designers and engineers from CIRM. As previously mentioned, these four standard features are: icons and terminologies, the grouping of key functions and controls, quickly accessible functions, and default system settings.

The S-mode correspondence groups conducted several studies to evaluate the usability of the standard features as proposed by CIRM. Details of these studies can be seen in (IMO, 2018b; Vu & Lutzhoft, 2018; Vu & Lutzhoft, 2019). The findings were circulated among members of the S-mode correspondence group for consideration.

Australia, as the coordinator, collected input from members and incorporated those to update the content of S-mode. There were four rounds of comments, resulting in four editions of S-mode. Decisions were made collectively and with each matter raised, the members needed multiple discussions to decide on following actions. Given the limited time available, the group had to adopt a strategy of “all or nothing”. If a solution immediately received mainstream support from the majority of stakeholders, it would be adopted. If a solution lacked immediate mainstream support and required a lot of discussion or additional development, the correspondence group would remove it from S-mode. On the one hand, this strategy meant the user studies conducted by the group had limited impact on the final outcome of S-mode. On the other hand, this practice allowed the group to achieve the goal of delivering S-mode by the assigned deadline.

The final draft of the S-mode guidelines was submitted to the IMO for consideration at NCSR 6 in 2019.

4.1.5. Final approval

During NCSR 6 in January 2019, the NCSR considered the final draft of the S-mode guidelines. The work was assigned to the Navigation Working Group, whose members were representatives of IMO member states and non-governmental organisations (NGOs). This work led to minor changes to the content of the draft. More importantly, changes were made to MSC.191(79) and SN.1/Circ.234 to ensure alignment with the S-mode guidelines.

The most important decision to made was the implementation date. There were three factors to considered: the need from users for improved usability of navigation systems, the merit of introducing the new standard features of the navigation displays, and the time needed for manufacturers to make the necessary changes to ensure conformity. It was also noted that three years was the common time needed for the IEC to update and finalise their regulations to stay aligned with revised IMO regulations. After extensive discussion, the following implementation dates were agreed:

- 1 January 2024 for Radar equipment, ECDIS, and INS
- 1 July 2025 for all other navigational displays on the bridge (IMO, 2019c)

Decisions made during NCSR 6 were subsequently approved by the MSC during their 101st session in July 2019 (IMO, 2019a). With this approval, S-mode officially became IMO document MSC.1/Circ. 1609 “Guidelines for the Standardisation of User Interface Design for Navigation Equipment”. This event concluded the development of S-mode.

4.2. Factors affecting the development of S-mode

Section 4.1 has summarised key events occurred during the development of the S-mode guidelines. Considering from the framework of joint activity, it is possible to group these key events into three phases, corresponding with the formation and execution of a joint activity. The three phases are as follow:

- Phase 1 – the main development of this phase was S-mode got accepted as an official part of e-Navigation, but there was no common goal among the involving parties. This phase started from the emergence of the S-mode concept and lasted until the adoption of the e-Navigation SIP in MSC 94, which gave S-mode an official place among e-Navigation solutions (IMO, 2014a). The participants involved during this period and their actions are discussed in sections 4.1.1 and 4.1.2.
- Phase 2 – the main objective of this phase was to determine a scope for S-mode. This phase began after the approval of S-mode as an e-Navigation solution in 2014 to the point when the scope of S-mode was finalised

in NCSR 5 in 2017 (IMO, 2017). Events happened during this phase and the involving actors are discussed in section 4.1.3.

- Phase 3 – the main objective of this phase was to finalise the contents of the S-mode guidelines. This phase began after NCSR 5 and ended when the S-mode guidelines were adopted in MSC 101(IMO, 2019a). The work done by the S-mode CG during this period is discussed in chapter 4.1.4.

This chapter discusses contextual factors affecting the development of the S-mode guidelines, considering perspectives of major stakeholders. These factors are presented following the chronological order of the three phases in the development of S-mode.

4.2.1. Support from influential maritime nations

Since the first introduction of the S-mode concept to NAV 53 in 2007, the NI and IFSMA had aimed to get S-mode accepted as a part of the e-Navigation initiative. This motion was supported after studies by Germany, Canada, and the Republic of Korea indicating potential benefits of S-mode for mariners, particularly in facilitating training and familiarisation and improving equipment usability (IMO, 2009c, 2010a, 2010b). It was this support from IMO member states that helped S-mode enter the agenda of e-Navigation. On the other hand, manufacturers of navigation equipment, represented by the CIRM, had expressed disapproval toward S-mode since it was first introduced.

From the perspective of joint activity, it can be argued that a joint activity did not exist between the involved stakeholders during this first development phase of S-mode. There was no common goal shared among the stakeholders. The CIRM had no intention to develop S-mode and were working on other initiatives. The IMO members supporting S-mode mentioned in the previous paragraph were not specifically attempting to develop S-mode. Rather, they were working to develop e-Navigation and S-mode just happened to match some of the e-Navigation agenda items. Only the NI and IFSMA were interested in developing the S-mode concept. These three groups of stakeholders each pursued their goals independently and their actions were not interdependent. Considering the lack of both a common goal and a level of interdependence between the involved stakeholders, a joint activity did not exist during this time (Klein et al., 2005).

Studies on the making of IMO regulations suggest that decisions made at the IMO are often influenced by politics and IMO negotiations could be interpreted as political contests between member states. Countries would enter a negotiation if a matter in question concerns their national interests and would use their influence at the Organisation to push for decisions aligning with their national agendas (Tan, 2005). A similar characteristic was observed in the case of S-mode. The process of getting S-mode accepted as an official e-Navigation agenda item can be interpreted as a political struggle between two groups, one supporting and one opposing S-mode.

During the key event of NCSR 1, both groups discussed and made the final decision whether to keep S-mode among e-Navigation solutions. The CIRM, IMPA, Japan, Netherland, and France did not support S-mode to be a part of e-Navigation while the NI, International Chamber of Shipping [ICS], INTERTANKO, Denmark, Norway, Germany, Republic of Korea [ROK], Australia, Marshall Islands, Panama, Kiribati, Nigeria, Poland supported S-mode.

It has not been possible to determine the exact motivation behind each stakeholder's decision to support or disapprove S-mode. However, an interview with two major stakeholders suggests that S-mode received major support from two groups of organisations: those with strong crewing interest and developed coastal states. The former supported S-mode as improved equipment standardisation could make training of ship crews more efficient. This group included maritime nations with strong influence at the IMO. The latter group was interested in improving navigation safety in their waters and S-mode could serve that interest by improving the usability of navigation system and, thus, reducing the probability of erroneous actions made by ship crews.

The group that opposed S-mode consisted of IMO members and organisations with strong interests in producing navigation equipment, especially the CIRM. While many complex arguments were made against S-mode, one persistent motivation from the manufacturers was that they wanted the freedom in designing their products by using innovative features as selling points. Considering the large number of manufacturers (as of February 2022, there were 105[3] members of CIRM) in such a small market as marine electronics, innovation and unique selling points are important to

[3] It should be noted that although not all 106 CIRM members are manufacturers of marine electronics, a majority of them are. There are also government agencies such as the UK Hydrographic Office or the US Coast Guard among CIRM members.

secure market share. Additionally, a standard interface could potentially lock in users, making it difficult for any subsequent change/update.

Previous studies on decisions making at the IMO suggest that IMO member states have unequal decision-making power and their ability to have an influence on IMO decisions depends on two factors: their willingness to enter a negotiation, and the resources they can commit to pursue favourable decisions (Argüello, 2021). In the case of this study, S-mode was supported by influential maritime nations and coastal states, and their support was instrumental in getting S-mode approved as an official IMO project.

4.2.2. The different perspectives on a scope of S-mode

Following the acceptance of S-mode as an e-Navigation solution in NCSR 1, the next step was to decide a scope for S-mode – what to standardise and how? Viewing from the framework of joint activity, it can be argued that a joint activity started to emerge during this phase as there was a common goal and a degree of collaboration between the involved stakeholders, who formed the S-mode CG. The stakeholders who participated during this period demonstrated a strong willingness to align their individual interests to maintain a common goal. This willingness was observed on both stakeholder groups who had opposed and supported S-mode during the first development phase discussed in the last section.

As the organisation representing manufacturers of navigation equipment, the CIRM acted to protect their members' interests. While opposed to the idea of fully standardised interfaces proposed by the original S-mode concept, the CIRM accepted that S-mode would be developed and wanted to be involved in the development process. The individual goal was to have manufacturers' inputs reflected in the outcome of S-mode since manufacturers would be the stakeholder obliged to implement S-mode in the end. On the other hand, the stakeholders who had supported S-mode during the first development phase did not do so because they specifically supported the original S-mode concept. Interviews with representatives of two major stakeholders indicate that the goal of these stakeholders had always been to improve the standardisation of interfaces and level of usability for navigation equipment. They supported the original S-mode concept because, at the time, the concept was considered capable of bringing the desired level of standardisation and usability. However, these stakeholders acknowledged the importance of incorporating manufacturers' input and were willing to work with the manufacturers to find a solution agreeable to both parties.

It was this willingness to compromise from both groups of stakeholders that allowed a common goal to emerge. With the common goal of determining the scope of S-mode, the work was carried out in the form of workshops and negotiations as discussed in section 4.1.3. While a joint activity did exist during this period, the collaboration within the S-mode CG was not always optimal and there were moments when members had conflicting opinions, hindering the collaborative efforts.

The main challenge to the collaborative effort occurred as members of the S-mode correspondence group came from different backgrounds and had different perspectives on the scope of S-mode. Human factors specialists and maritime regulatory agencies envisioned S-mode as a set of human factors principles for designing interfaces of navigation systems. Manufacturers, represented by the CIRM, envisioned S-mode to be detailed specifications of certain features on the interfaces of navigation systems. Such differences in perspective occurred because most members of the S-mode CG, except for the CIRM, had limited knowledge of what manufacturers require from an implementable technical regulatory document. The group focused dominantly on studying the requirements of seafarers who are the end-users of navigation equipment while less focus was given to the need of equipment manufacturers who would implement S-mode directly.

Manufacturers, who dominantly come from engineering backgrounds, tend to approach knowledge in an empirical, pragmatic, and utilitarian manner (Koen, 2003). In the case of S-mode, the main concern of manufacturers when implementing a regulatory document is whether they can conduct tests to certify their products as compliant. To this end, manufacturers require detailed technical specifications with testable criteria. To manufacturers, the human factors principles, which were developed by human factors specialists and form the first part of the S-mode guidelines, were too generic to be implemented in actual design practices. In other words, other stakeholders had envisioned S-mode in a format incomprehensible or practically unusable for equipment manufacturers.

In summary, it was the lack of consideration given to the requirements of manufacturers that delayed the collaborative efforts and was the main reason why it took so long for members of the S-mode correspondence group to reach agreement on a scope of S-mode. This issue can be interpreted as a communication gap between manufacturers and other members of the S-mode CG. In section 5.2, the authors will argue that the structure and working principles of the IMO itself play a role behind these shortcomings.

4.2.3. Internationally-collaborative user-centred design

After the scope of S-mode was finalised in 2018, the S-mode CG started working to develop the contents of the S-mode guidelines. This work, as discussed in section 2, followed the principles of a user-centred design process. However, this development work was undertaken by an IMO correspondence group and followed the working arrangement of IMO correspondence groups.

The first factor to consider is the fact that the S-mode CG, while attempting to follow standard steps in a UCD process as recommended in ISO 9241:2010 (ISO, 2010), did so in a loosely structured manner. This practice directly resulted from the working principle of an IMO correspondence group. Members of the S-mode CG carried out work on their own and communicated via emails with Australia acting as the coordinator.

In an industrial setting, for a user-centred design process to be successful, it is recommended that the application of user-centred design activities and methods be carefully planned and managed throughout the development process, and to maintain a good flow of information on users to the relevant parts of the development team (Maguire, 2001). Such recommended practices are not easily achievable within the working arrangement of an IMO correspondence group, specifically the S-mode CG in this case. Members of the S-mode CG did not have a detailed work plan which described the exact tasks to be carried out and methods to perform each task. The reason was that members joined the S-mode CG on a voluntary basis and each member was an organisation with its own resources and autonomy. Therefore, members of the S-mode CG, for the most part, decided on their own what they would do to contribute to S-mode. Although such decisions were communicated to other members and agreed upon, such practice resulted in a loose structure in the coordination within the S-mode CG. As a result, there was a lack of coherence in the way that the S-mode correspondence group performed different user-centred design activities to develop S-mode. For instance, the first edition of the four interface features to be standardised by S-mode was developed by CIRM while NI and the ROK were still conducting studies to understand how seafarers operate navigation equipment in practice.

Another aspect of the working arrangement of an IMO correspondence group that influenced the development of S-mode was the methods of communication. Since members were physically located in different locations worldwide and communication was via emails, it took time to exchange ideas and reach agreements. With S-mode, a majority of the development work was undertaken by the NI, CIRM, Australia, and ROK. Their results were communicated to other members of the S-mode CG for feedback and decisions were made collectively. The use of email correspondence meant there were, in many instances, delays in information exchange between members, which affected the decision-making process. Combining with the deadline of 2019 given by the IMO, the S-mode CG had to adopt a negotiation strategy of "immediate consensus or nothing" when making collective decisions regarding the contents of S-mode, following the efficiency-thoroughness trade-off (ETTO) principles (Hollnagel & Hollnagel, 2009). In order to meet the assigned completion date, the group essentially had to sacrifice the level of thoroughness in which the standard interface features introduced in S-mode were developed with usability in mind.

In summary, the working arrangement of an IMO correspondence group reduced the coherence and the effectiveness of communication between participants in the development of S-mode, which directly affected the final content of the S-mode guidelines.

5. Discussion

The findings of this study share commonalities with published studies on the development of maritime regulations at the IMO. However, the case of S-mode focuses on the specific of maritime human factors and provides additional insights into the status of human factors application in the design of shipboard navigation system as well as the role of the IMO in facilitating such practice.

5.1. Human factors consideration for shipboard navigation system

As discussed in section 2, there are still cases of shipboard equipment with usability issues, occurred due to the lack of human factors consideration during the design process. The development of S-mode provides some explanation as to why this is the case.

One of the reasons could be that manufacturers are not able to effectively obtain user inputs to improve their products. In the first ten years following the emergence of e-Navigation (2006-2016), manufacturers actively consulted seafarers through organisations such as the NI to study what user needs from shipboard systems to do their jobs. However, manufacturers often asked questions which were difficult for seafarers to answer. Common questions could be "*We have decided that we are going to give you a system that you want. What do you want? We will build it for you*" and the common reply from seafarers would be "*Just better stuff than we have*". Seafarers are not equipment designers and, therefore, cannot provide bridge system specifications that make sense to, and are immediately useful to, equipment manufacturers. Manufacturers had a vision for more sophisticated systems and were frustrated when seafarers could not explain what such systems would be like. This example demonstrates that manufacturers are not able to perform user-centred design effectively. It is possible that this situation can be connected to the absence of topics on human factors and user-centred design in curriculums for educating maritime system designers and naval architects (Abeysiriwardhane, 2017), and the difference in world views between human factors specialists and engineers (Petersen et al., 2011). This difference in perspectives between human factor specialists and engineers will be discussed in more details in section 5.2.

Additionally, to address human factors properly in an industrial setting, resources are needed. In the case of S-mode, from 2008-2014, the NI was constantly seeking resources from all potential sources to develop S-mode based on the original concept. The plan was to develop prototype interfaces for a wide range of displays on the bridge and test them with seafarers to identify optimal features for standardised interfaces. The NI estimated that 1 million pounds would be necessary for such a project and drafted a proposal to IMO member states. Some member states were interested, including Ireland, Singapore, Norway, and Canada. In the end, however, the budget plan did not get approved. The NI then changed the plan to develop web-based simulators, which would cost half the original budget to complete. This alternative proposal also did not receive funding. Ultimately, the whole research plan was abandoned due to a lack of resources and the NI could only perform a couple of online surveys to study user needs.

Another challenge with human factors engineering is the lack of a centralised approach for R&D in the maritime industry. Companies may have their own R&D department and flag states often invest through their national research institutions, but there is no industry-wide regime. In the case of S-mode, even as an international initiative, there was no central budget and stakeholders conducted much of the work independently using their own resources.

Finally, there is a lack of an effective communication channel between seafarers at the "sharp end" and people at the "blunt end" such as the IMO. Seafarers are practitioners with first-hand knowledge of current issues in shipping, especially when it comes to usability of shipboard equipment. They are represented by organisations such as the NI and IFSMA, but these organisations are not well-resourced enough to shape an influence at the IMO. At the same time, IMO delegates are often civil servants and even those with a technical background may have left the "sharp end" many years before joining the IMO and their experience is no longer relevant to understanding contemporary issues, especially with the current rate of technological advancement.

In summary, events during the development of the S-mode guidelines indicate that human factors is still an area requiring further development in the maritime industry, and regulatory instruments play an important role in facilitating such development

5.2. The need for implementable regulatory instruments

Documents from regulatory agencies such as the IMO play a critical role in shaping directions in the maritime industry, maritime human factors included. There is little incentive for manufacturers to implement something without regulatory requirement. The fact that standard features introduced in the S-mode guidelines are mandatory significantly increases the impact of the guidelines.

As discussed in section 4.2.2, there existed a communication gap between equipment manufacturers and other stakeholders involved in developing technical regulatory documents. In the case of S-mode, it was mainly the gap between human factors specialists and equipment manufacturers with dominant engineering backgrounds.

To the author's knowledge, there was no published study investigating this communication gap in the context of marine electronics manufacturing. However, Bader and Nyce (1998) investigate a similar communication gap between social scientists and software developer. They observe that cultural and social knowledge, while provides useful insights on users, is not useful for software developers. The main reason is that social scientists and software developers perceive such knowledge differently, and the way researchers present their findings is not comprehensible for software developers. Petersen et al. (2011) use the term "two tribes problem" to refer to this problem. They explain that scientists and engineers belong to different groups (or tribes) of professionals, and reports of academic studies are drafted by people belonging to the scientist tribe following a format of scholarly writing which, while familiar to the scientists, does not make sense to people of the engineering tribe. A method to address this gap, as Petersen et al. (2011) suggest, is to initiative changes from the side of social scientists in the way studies are conducted and reported, aiming to generate knowledge comprehensible for the engineering community. To this end, it is suggested that researchers consider, in the conduct of studies on human factors-related subjects, both the end-users and the people who would implement the research findings. Transferring these findings from the context of software development to the context of marine electronics in the case of S-mode, it is important to consider both the end-users and equipment manufactures when developing relevant regulatory instruments. Specifically, for a regulatory instrument to be effectively implemented, it must be specific and contain testable criteria to evaluate compliancy.

The IMO, however, is not the most capable organisation for making technical documents. Especially in the case of technical documents on the topic of interaction design, the IMO tend to develop high-level regulations with generic criteria (Mallam & Nordby, 2018). IMO delegates are often civil servants, and they may lack the necessary experience to understand technical issues. When a technical matter requires comments/decisions from IMO members, the matter is often discussed at the national level and each member state will then give their delegates a script describing their agenda to be published at the IMO. Such published agendas tend to be generic and not targeting specific technical questions. The discussions whether to include or excluded S-mode among e-Navigation solutions during NCSR 1 as summarised in section 4.1.2 is an example of this practice.

Another factor to consider is that IMO meetings are not held frequently. Most of the meetings are annual and a lot of time passes between meetings. Also, IMO processes are inflexible and tightly controlled, with specific administrative procedures to be followed. On the one hand, this practice ensures a certain stability for the industry to function. If changes are made frequently, it will be very costly for the stakeholders to keep up with all the changes. Some stability is important as it helps to achieve some standardisation and allows people time to learn and be familiar with the new situation each time a change is adopted. On the other hand, however, such multiple-step processes do not support innovation and it takes a long time for new issues to come through at the IMO.

On the contrary, technical organisations such as the International Association of Marine Aids to Navigation and Lighthouse Authorities [IALA] are formed mainly by people with technical backgrounds, have more frequent meeting sessions, and they work intersessionally. As a result, it would be best if the IMO focuses on developing high-level performance standards, possibly goal-based, and technical organisations like the IEC or IALA develop detailed technical specifications. This approach is already in practice, but there are currently several technical organisations handling different topics – the IHO handles the ENC, the IALA deals with aids to navigation, and the marine department of the IEC deals with marine electronic systems. A more optimal structure for coordinating and regulating shipping at an international level could be achieved by merging all relevant technical organisations or at least joining them with regards to policy, resulting in a structure as illustrated in figure 1.

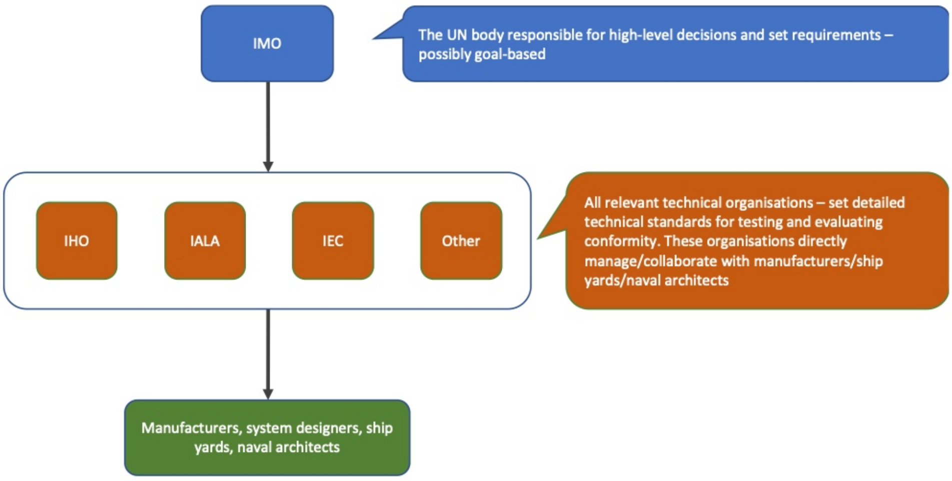

Figure 1. Suggested structure for organising stakeholders involved in developing and implementing human factors regulatory instruments in the maritime industry

In summary, the application of human factors in the maritime field, particularly in the design of navigation systems, is still limited. This status can be changed if manufacturers are given regulatory incentive while still having leeway for innovation. However, the working model of the IMO does not facilitate the development of detailed technical documents that meet the requirements of manufacturers. A better working model is for the IMO to focus solely on high-level regulatory instruments and collaborate with other specialised technical organisations such as the IHO or IEC to develop detailed regulations for manufacturers to implement.

Finally, changes happen slowly in the maritime regulatory field and any improvement needs to be implemented gradually, maritime human factors included. It is unrealistic to expect rapid or drastic changes.

6. Conclusions

This study provides a detailed description of key events occurred during development of circular MSC.1/Circ.1609 Guidelines for the Standardisation of User Interface Design for Navigation Equipment, known unofficially as the "S-mode" guidelines. Using multiple sources of data, this study has identified influential factors in the development of S-mode and connected to the larger issue of human factors application in the design of marine electronics. In specific:

- The development of the S-mode guidelines was shaped by three factors: the support from influential maritime states, the inclusion of inputs from both seafarers and equipment manufacturers, and the conduct of a multi-stakeholder design project following the working arrangement of IMO correspondence groups
- Decisions at the IMO are highly political. Member states use political influence to push their agenda and form coalitions based on aligned interests to strengthen their decision-making power. It is the largest maritime states that have the most influence and decisions at the IMO are often made in alignment with the agendas of those influential members. Future initiatives similar to S-mode should aim to secure support from influential IMO members to increase the probability of being adopted/endorsed at the Organisation.
- Regulatory incentive plays a major role in improving human factors consideration in shipping. However, to be effectively implemented, human factors regulatory documents must account for the requirements of not only the end users but also the implementers which, in the case of marine electronics, are equipment manufacturers. Manufacturers are mainly concerned with getting their products approved by regulatory bodies and require detailed technical specifications with testable criteria to demonstrate compliance
- While being the specialised UN agency for safety and security in shipping, the IMO is not the most capable stakeholder for making detailed technical documents that meet the requirements of manufacturers. Delegates at the IMO are civil servants, and few have the expertise to understand contemporary technical issues in shipping. Furthermore, IMO meetings are not held frequently, and a lot of time passes between meetings. On the other hand, technical organisations such as IALA and IEC are formed by technical specialists, have more frequent meeting sessions, and work intersessionally. As a result, the IMO should focus on generic high-level requirements and collaborate with specialised technical organisations to supplement such high-level requirements with detailed technical specifications
- The IMO follows a rigid and multi-step procedure for making decisions. When it concerns unfamiliar topics such as maritime human factors, the IMO often starts with the lowest-level regulatory instruments, namely guidelines or recommendations and can raise the level if the matter in question is considered important in the industry. As a result, changes happen slowly in the maritime industry and any improvement needs to be implemented gradually, maritime human factors included. It is unrealistic to expect or aim for rapid change

This study is, to the authors' knowledge, the first one that investigates the development of an IMO regulatory instrument concerning human factors in the design of navigation equipment and should be considered when starting similar IMO projects in the future.

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Appendix 1

The following table 1 lists all documents used as the first data source for this study, as mentioned in section 3.2:

Table 1. List of official records issued by the IMO and relevant maritime organisations on the development of S-mode

Sessions/Meetings	Issuing organisation	Document title	Period
COMSAR 11	COMSAR	COMSAR 11/WP.4 - Development of an e-Navigation strategy - Report of the Working Group	2007
		COMSAR 11/18 - Report to the Maritime Safety Committee	
NAV 53	NAV	NAV 53/13 - Development of an e-Navigation strategy - Report of the Correspondence Group on e-Navigation	
		NAV 53/22 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NAV 53	
NAV 54	NAV	NAV 54/INF.3 - Development of an e-Navigation strategy - Supporting material submitted by the United Kingdom	2008
		NAV 54/13/1 Development of an e-Navigation strategy - The concepts of S-mode for onboard navigation displays, submitted by the International Federation of Shipmasters' Associations (IFSMA)	
		NAV 54/13 - Development of an e-Navigation strategy - Report of the e-Navigation Correspondence Group, submitted by the United Kingdom	
		NAV 54/25 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NAV 54	
MSC 85	MSC	MSC 85/26 - Report of the Maritime Safety Committee on its eighty-fifth session	

		MSC 85/26/Add.1 - Report of the Maritime Safety Committee on its eighty-fifth session	
NAV 55	NAV	NAV 55/INF.8 - Development of an e-Navigation strategy implementation plan - Mariner needs for e-Navigation - Supporting material submitted by the International Federation of Shipmasters' Association (IFSMA)	2009
		NAV 55/INF.9 - Development of an e-Navigation strategy implementation plan - Results of a worldwide e-Navigation user needs survey, submitted by Germany	
		NAV 55/21 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NAV 55	
MSC 86	MSC	MSC 86/23/4 - Work Programme - A coordinated approach to the implementation of the e-Navigation strategy	
		MSC 86/26 - Report of the Maritime Safety Committee on its eighty-sixth session	
	NMA	Rapport fra MSC 86	
NAV 56	NAV	NAV 56/INF.6 - Development of an e-Navigation strategy implementation plan - Findings of Canadian e-navigation User Needs Survey, submitted by Canada	2010
		NAV 56/INF.10 - Development of an e-Navigation strategy - Consideration for the gap analysis of e-Navigation, submitted by the Republic of Korea	
		NAV 56/8 - Development of an e-Navigation strategy implementation plan - Report of the Correspondence Group, submitted by Norway	

		NAV 56/INF.13 - Development of an e-Navigation strategy implementation plan - Background of the Development of the preliminary draft guidelines for usability evaluation of navigation equiopment, submitted by Japan	
		NAV 56/8/9 - Development of an e-Navigation strategy implementation plan - Usability assessment methodology for navigational equipment, submitted by Japan	
		NAV 56/WP.5/Rev.1 - Development of an e-Navigation Strategy Implementation Plan	
		NAV 56/20 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NAV 56	
STW 42	STW	STW 42/6 - Development of an e-Navigation strategy development plan - Report of the Correspondence Group on e-Navigation, submitted by Norway	2010-2011
		STW 42/14 - Report to the Maritime Safety Committee	
NAV 57	NAV	NAV 57/6/3 - Development of an e-Navigation strategy implementation plan - User preference on the priority of user needs and functions to be implemented, submitted by the Republic of Korea	
		NAV 57/6 - Development of an e-Navigation strategy implementation plan - Report of the Correspondence Group on e-Navigation to NAV 57, submitted by Norway	
		NAV 57/15 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NAV 57	
NAV 58	NAV	NAV 58/6 - Development of an e-Navigation strategy implementation plan - Report of the Correspondence Group on e-Navigation to NAV 58, submitted by Norway	2012

		NAV 58/WP.6 rev.1 Annex 2 - Report of the Working Group on e-Navigation - Preliminary list of potential e-Navigation solutions	
		NAV 58/14 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NAV 58	
NAV 59	NAV	NAV 59/6/1 - Development of an e-Navigation strategy implementation plan - Design usability principles for e-Navigation solutions and risk control options, submitted by Australia	2013
		NAV 59/6 - Development of an e-Navigation strategy implementation plan - Report of the Correspondence Group on e-Navigation to NAV 59, submitted by Norway	
		NAV 59/6/5 - Development of an e-Navigation strategy implementation plan - Comments on the Correspondence Group's report to NAV 59, submitted by Australia	
		NAV 59/6/6 - Development of an e-Navigation strategy implementation plan - Report of the Correspondence Group on e-Navigation to NAV 59, submitted by the International Chamber of Shipping (ICS) and BIMCO	
		NAV 59/20 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NAV 59	
NCSR 1	NCSR	NCSR 1/INF.5 - Development of an e-Navigation strategy implementation plan - Background information related to the development of e-Navigation, submitted by Norway	2014
		NCSR 1/INF.7 - Development of an e-Navigation strategy implementation plan - Report on the future direction for improving existing onboard system regarding detailed CMDS of e-Navigation implementation, submitted by the Republic of Korea	

		NCSR 1/INF.16 - Development of an e-Navigation strategy implementation plan - Report on the international joint test for e-Navigation solutions in Korean waters as a first step toward implementing a global e-Navigation testbed, submitted by Denmark, the Republic of Korea and Sweden	
		NCSR 1/9 - Development of an e-Navigation strategy implementation plan - Report of the Correspondence Group on e-Navigation, submitted by Norway	
		NCSR 1/9/1 - Development of an e-Navigation strategy implementation plan - Draft guidelines developed to support the e-Navigation strategy, submitted by Norway	
		NCSR 1/9/3 - Development of an e-Navigation strategy implementation plan - Comments on the report of the Correspondence Group on e-navigation to NCSR 1, submitted by the Comité International Radio-Maritime (CIRM)	
		NCSR 1/28 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NCSR 1	
MSC 94	MSC	MSC 94/18/8 - Work Programme - Development and implementation of e-Navigation, submitted by Australia, Denmark, Germany, the Netherlands, Norway, the Republic of Korea, Sweden, IHO, IALA, ICS, BIMCO, CIRM, InterManager and the Nautical Institute	
		MSC 94/21 - Report of the Maritime Safety Committee on its ninety-fourth session	
	NMA	Rapport fra MSC 94	
NCSR 2	NCSR	NCSR 2/INF.11 - E-Navigation Strategy Implementation Plan - Consideration of survey-based user requirements for the development of S-mode, submitted by the Republic of Korea	2015-2016

		NCSR 2/23 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NCSR 2	
MSC 95	MSC	MSC 95/19/8 - Work Programme - Implementing e-Navigation to enhance the safety of navigation and protection of the marine environment, submitted by Australia, Denmark, Finland, Germany, the Netherlands, Norway, the Republic of Korea, ICS, IALA, BIMCO, CLIA, InterManager and the Nautical Institute	
		MSC 95/19/12 - Work Programme - Implementing e-Navigation to enhance the safety of navigation and protection of the marine environment, submitted by Australia, the Republic of Korea, International Association of Institutes of Navigation, International Federation of Shipmasters' Associations, InterManager and the Nautical Institute	
		MSC 95/19/14 - Work Programme - Comments on implementing e-Navigation to enhance the safety of navigation and protection of the marine environment, submitted by the International Hydrographic Organisation	
		MSC 95/22 - Report of the Maritime Safety Committee on its 95th session	
		MSC 95/22/Add.2 - Report of the Maritime Safety Committee on its 95th session	
	NMA	Delegasjonsrapport MSC 95	
NCSR 3	NCSR	NCSR 3/INF.17 - An International Workshop on the development of guidance on the S-mode of operation of navigation equipment, submitted by the Republic of Korea	

		NCSR 3/28/1 Development of guidance on the Standardized (or S) Mode of operation of navigation equipment, submitted by Australia, the Republic of Korea, InterManager, The Nautical Institute (NI), International Association of Institutes of Navigation (IAIN), International Federation of Shipmasters' Associations (IFSMA), International Electrotechnical Commission (IEC) and Comité International Radio-Maritime (CIRM)	
		NCSR 3/29 - Report to the Maritime Safety Committee	
	NMA	Delegasjonsrapport NCSR 3	
NCSR 4	NCSR	NCSR 4/INF.8 - Development of guidance on Standardised (or S) Mode of operation of navigation equipment (including plans for a testbed by the Republic of Korea in 2017), submitted by Australia, the Republic of Korea, InterManager and the Nautical Instittue	2017-2018
		NCSR 4/29 - Report to the Maritime Safety Committee	
	IFSMA	Report on IMO meeting NCSR 4 (06.03. - 10.03.2017)	
	NMA	Delegasjonsrapport NCSR 4	
e-Navigation Underway Asia-Pacific Conference	IALA	Conference Report - e-Navigation underway 2017 Asia - Pacific - implementing e-Navigation in the Asia-Pacific region, 18 to 20 June, 2017, Lotte Hotel, Jeju Island, Republic of Korea	
NCSR 5	NCSR	NSCR 5/INF.13 - Guidelines on Standardized Modes of Operation, S-mode - Results of the S-mode user preference test, submitted by the Republic of Korea	
		NCSR 5/INF.15 - Research document on the human cognitive processes in maritime icon display standardisation and automated systems, submitted by Australia	

		NCSR 5/7 - Guidelines on Standardised modes of operation, S-mode - Draft guideline, submitted by Australia, the Republic of Korea, BIMCO, the CIRM, the IAIN, the IEC, InterManager, and the Nautical Institute	
		NCSR 5/23 - Report to the Maritime Safety Committee	
	IFSMA	NCSR 5 Brief - 19-23 Feb 2018	
	NMA	Delegasjonsrapport NCSR 5	
NCSR 6	NCSR	NCSR 6/INF.13 - Guidelines on Standardized Modes of Operation, S-mode - Practical user interface test methods for standardization and improvement of navigation equipment, submitted by the Republic of Korea	2018-2019
		NCSR 6/7/1 Guidelines on Standardised Modes of Operation, S-mode - Comments on document NCSR 6/7 - Icons for control of chart display functions, submitted by Australia and the International Electrotechnical Commission (IEC)	
		NCSR 6/7/2 Guidelines on Standardised Modes of Operations, S-mode - Comments on document NCSR 6/7, submitted by Comite International Radio-Maritime (CIRM) and the Nautical Institute (NI)	
		NCSR 6/7/3 Guidelines on Standardised Modes of Operation, S-mode - Comments on document NCSR 6/7, submitted by the International Chamber of Shipping (ICS)	
		NCSR 6/7 Guidelines on Standardised modes of Operation, S-mode - Report of the Correspondence Group	
		NCSR 6/WP.4 Report of the Navigation Working Group	
		NCSR 6/23 - Report to the Maritime Safety Committee	

		NCSR 6/23/Add.1 - Report to the Maritime Safety Committee	
	IFSMA	NCSR 6 Report	
	NMA	Delegasjonsrapport NCSR 6	
MSC 101	MSC	MSC 101/24 - Report of the Maritime Safety Committee on its 101st session	
	NMA	Delegasjonsrapport MSC 101	

Appendix 2

This appendix contains the interview questions used for the semi-structure interviews of the major stakeholders involved in the development of S-mode, as discussed in section 3.2. The questions are presented in the form of a table. Table 2 below is the exact copy of the same table sent to the selected stakeholders in preparation for the interviews.

Table 2. Key events during the development of S-mode and questions to consider in each event

Period	Event	What happened?	Questions to consider
2005-2008	2005-2007 - An idea proposed by the NI & IFSMA	The emergence of the S-mode concept as a standard display mode which can be activated by a single button	• How did the NI and IFSMA came up with the idea of S-mode?
	2007 – NAV53 – IMO considered S-mode for the first time	The e-Navigation Corresponded Group, chaired by the UK, considered the S-mode concept. The ultimate decision was to decline endorsement as the S-mode concept was considered to be too premature at the time	• How did S-mode get to be considered by NAV in the first place? • Why did NAV decide to turn down the original S-mode concept in NAV53 (2007)? Was it the fact that the concept was premature at the time the only reason to turn it down?
2010	NAV 56	Norway took over as the coordinator of the e-Nav correspondence group from the UK	• Why did Norway take over the role of co-ordinating the development of e-Navigation from the UK? • What happened after Norway took over? Is this really a critical moment for S-mode?
2014	NCSR 1	CIRM proposed to remove S-mode from e-Navigation, stating issues with the concept. However, this proposal was not accepted	• How did stakeholders discuss and decide not to remove S-mode? What was the opposition/counterargument to CIRM's proposal?
2015	MSC 95	IMO officially adopted S-mode as a part of the post-biennia agenda of the MSC. An informal S-mode Correspondence Group was formed under the coordination of Australia	• Why did Australia assume the role of coordinating the informal S-mode correspondence group? • The scope of S-mode was not finalised during 2015-2017. What were the arguments between involved parties during that time? Why was it not possible to agree on a scope of S-mode, despite numerous discussions between involved parties?
2017	"e-Navigation underway 2017 Asia-Pacific" Conference – June 2017	CIRM proposed a new scope for S-mode, which received support from many Conference attendees. This support eventually led to the official adoption of CIRM's proposal during NCSR5	• What happened during the conference that led to the approval of CIRM's proposal? What were the arguments/discussions between Conference attendees?

2018	NCSR 5 in March 2018	The finalisation of the scope for S-mode	• Based on corresponding emails among members of the S-mode correspondence group following the e-Nav Conference in Jeju, Korea, it appears that decisions were already made to adopt CIRM's proposal even before the official NCSR 5 sessions. Was this really the case? • Which arguments/agreements were made during the official NCSR5 sessions? Did those arguments/agreements have any impact on the final decision to adopt CIRM's proposal? • In other words – When did the involved parties finally agree on a common scope for S-mode, based on CIRM's proposal? And what made them agree with each other?
2018	Main development of the S-mode guidelines – user studies were conducted, and the text of the guidelines finalised	Norway, Australia, and Korea conducted user studies. Only some of their findings were adopted into the S-mode guidelines.	• The tests had limited impacts on the actual guidelines. The consideration was quick and if something required extensive consideration/modification, it would be removed from the guidelines. Examples include the icons used for control functions on Radar systems. Do you agree with this observation? If yes, why do you think the test results were not adopted more thoroughly into the S-mode guidelines? If no, what was your observation on the extent to which results of the usability studies were applied in the S-mode guidelines?
2019	NCSR 6 in January 2019	The final discussion and adoption of the S-mode guidelines	• The main decision to make during NCSR6 was the date S-mode would enter into force. It was a result of a long and tense discussion. How did the involved parties arrive on an agreed date? • Do you believe S-mode have any real impact on the industry, especially for the users (seafarers) and manufacturers?

Annex 5 – Task analysis of marine navigation

Task analysis of marine navigation

This document outlines the navigation tasks performed by seafarers on merchant ships, information required for each task, and the sources of such information. The tasks are divided into three main parts of a voyage: the quay and harbour waters, the fairway/coastal areas, and the open sea. These tasks are resulted from several analyses of marine navigation done by Sanquist et al. (1994), Røed (2007), Procee et al. (2017), Van Westrenen (1999), and Koester et al. (2007).

Among the tasks, some are involved in almost every part of the voyage and are repeated many times. Those tasks are collision avoidance, conning, and plotting position. To avoid repeating, such tasks are presented in separated tables under "Repeated tasks" sub-section, below the "Main tasks" section.

"*Marine navigation is a blend of both science and art*" (Bowditch, 2017, p. 1). As a result, many navigation tasks are performed not using analogue data presented on electronic systems but rather based on intuitive observation and feeling of the navigators. For such tasks, it is difficult to determine which information is being processed in the mind of the navigators. Still, given the potential application of augmented reality technology in such scenarios, we highlight such sources of information in light orange and leave the investigation for another projects.

Texts highlighted in yellow concern unresolved issues.

Before viewing the tasks, readers are encouraged to view the list of terminologies used specifically in this document to avoid potential misunderstandings. The terminologies are listed in the following sub-section.

Terminologies

This document uses two terminologies which, if not being understood correctly, can confuse readers. This sub-section provides explanations to all those terms:

- Radar operational display area – according to MSC.191(79) (IMO, 2004), clause 5.1.3, the display of navigation systems should be clearly separated into an operational display area which contain (e.g. radar, chart) and one or more user dialogue areas (e.g. menus, data, control functions). The operational display area on Radar is the radar image.
- ECDIS operational display area – similar to Radar operational display area, ECDIS operational display area refers to the area of display used to graphically present the ENC information.

The navigation tasks are presented in the following sections together with corresponding functions/information from navigation systems intended to support the tasks.

Main tasks

Departing – Manoeuvring from quay This part of the voyage happens after all lines have been casted off and the vessel is free to move away from berth. Tasks performed in this phase mainly involve ship handling.						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Availability in Bridge Equipment**	**Notes**
Determine environmental status	Determine water level		Tidal information	Publication from the Hydrographic Office, such as the UKHO Total Tides.	ECDIS (optional) – as required by S-52 (IHO, 2010) clause 2.1.2.	
	Determine wind direction and speed		Wind direction and speed	Wind vane and Anemometer. Publication from the Hydrographic Office.	Anemometer display. INS (optional) – as required by MSC.252(83), clause 7.5.2.1, to be displayed on INS navigation control display. This requirement means that signals from the anemometer can be integrated into INS.	
	Determine current direction and speed		Set and drift	Publication from the Hydrographic Office, such as the Admiralty Manual of Tides. Real-time calculation of Set and Drift	ECDIS (mandatory) – as required by MSC.232(82), Appendix 3, Clause 8, in the form of tidal stream vectors. INS (optional) – as required by MSC.252(83), clauses 7.3.3 and 7.5.2.1, in the forms of either tidal data on the ECDIS component of INS or set and drift values on INS navigation control display. On conventional bridges (non-integrated), it is not required to display Set and Drift values. Still, most modern Radar systems have the functionality to automatically calculate and display Set and Drift, often by calculating the offset between CTW,STW and COG,SOG (Bole et al., 2005).	
Manoeuvre from quay	See section "Precision manoeuvring"					
Navigating the fairway/coastal areas						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Monitor the sailing	Monitor course	Monitor Heading	Heading	Compass (HDG)	Heading indicator (Gyrocompass) Radar (mandatory) – as required by MSC.192(79), clauses 5.19.3 and 8.1. Data from Heading sensors must be inputted into Radar. ECDIS (mandatory) – as required by MSC.232(82), clause 11.4.8. Data from heading sensors must be	

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					inputted into ECDIS. INS (mandatory) – as required by MSC.252(83), clause 7.3.2, to be displayed on INS navigation control display.	
		Monitor Course	Course	GNSS sensors (COG)	GNSS unit Radar (mandatory) – as required by MSC.192(79), clause 5.28.6, among other own ship AIS data. ECDIS (mandatory) – as required by MSC.232(82), Appendix 3, clause 11. INS (mandatory) – as required by MSC.252(83), clause 7.3.2.	
	Monitor rudder angle		Rudder angle	Rudder angle indicator	Rudder angle indicator – as required by SOLAS V/19 INS (mandatory) – as required by MSC.252(83), clause 7.5.2.1, to be displayed on INS navigation control display.	
	Monitor the track with radar	Check radar image to ensure radar picture is as expected	Radar image	Radar operational display area	Radar (mandatory) (standalone or as a part of INS)	
		Check own ship Heading Line	Heading Line	Heading Line	Radar (mandatory) (standalone or as a part of INS)	
		Check Parallel Index Lines	Parallel Index	Parallel Index	Radar (mandatory) (standalone or as a part of INS)	
		Operate measuring tools if necessary	EBL VRM	EBL VRM	Radar (mandatory) (standalone or as a part of INS)	
	Continuous monitoring of position in real time	Confirm the ship position is as expected	The ship's position relative to surrounding landmarks	Visual observation of landmarks in vicinity The display of own ship and landmarks on ECDIS and Radar	ECDIS (standalone or as a part of INS) Radar (standalone or as a part of INS)	
			Bearing to landmarks	EBL	ECDIS (standalone or as a part of INS) Radar (standalone or as a part of INS)	
			Cross track distance value	XTD	Not required, according to performance standards. However, many ECDIS systems have this information displayed to support route monitoring.	
Monitor external environment	Monitor and determine changes to wind direction and speed		Wind direction and speed	Wind vane and Anemometer. Publication from the Hydrographic Office.	Anemometer display. INS (optional) – as required by MSC.252(83), clause 7.5.2.1, to be displayed on INS navigation control display. This requirement means	

					that signals from the anemometer can be integrated into INS.	
	Monitor and determine changes to current direction and speed		Set and drift	Publication from the Hydrographic Office, such as the Admiralty Manual of Tides. Real-time calculation of Set and Drift	ECDIS (mandatory) – as required by MSC.232(82), Appendix 3, Clause 8, in the form of tidal stream vectors. INS (optional) – as required by MSC.252(83), clauses 7.3.3 and 7.5.2.1, in the forms of either tidal data on the ECDIS component of INS or set and drift values on INS navigation control display. On conventional bridges (non-integrated), it is not required to display Set and Drift values. Still, most modern Radar systems have the functionality to automatically calculate and display Set and Drift, often by calculating the offset between CTW,STW and COG,SOG (Bole et al., 2005).	
	Monitor sea stage		The amount of clutters on radar screens	Radar operational display area	Radar	
	Determine visibility		Distance to the furthest visible landmarks	Visual sighting of landmarks Echoes of landmarks on Radar screens VRM	Radar	
	Locate rain or snow squalls		Location of rain or snow squalls	Visual sighting of squalls Clutters on Radar screens VRM and EBL	Radar	
Plot position	Plot position using suitable methods, considering prevailing conditions. See details in "Repeated tasks" section.					
Monitor and adjust Radar settings to ensure optimal performance	Operate Radar performance functions	Brightness adjustment	Brightness level	Brightness level	Radar	
		Change scale	Range scale	Range scale	Radar	
		Adjust Gain	Gain level	Gain level	Radar	
		Adjust Rain & Sea anti-clutter controls	Rain and Sea anti-clutter settings	Rain and Sea anti-clutter settings	Radar	
	Operate Radar optional functions	Off-centre	Off-centre display function	Off-centre display function	Radar	
		Adjust Display Mode	Motion settings	Motion settings	Radar	
		Check gyro heading accuracy	Heading information	HDG	Radar	
			Course data	COG/CTW	Radar	
		Check stabilisation settings	Stabilisation source (Sea/Ground)	Stabilisation source	Radar	
Prepare for course change	Check passage plan		The passage plan	The active route displayed on the ENC Route information WP information	ECDIS	
	Check traffic situation		Known, unknown, and expected traffic	Target echoes and AIS data displayed on Radar Visual observation of traffic situation	Radar	Additional information may be available from VTS
	Check next course with ship's present position	Confirm that the new course is suitable	The suitability of next course	Radar operational display area EBL and VRM Parallel Index Lines	Radar	
			AtoN to support course change	Landmarks/Leading Lines displayed on	ECDIS Radar	

				ECDIS and Radar operational display areas Visual observation of Landmarks/Leading Lines		
	Check steering condition		Rudder angle	Rudder angle indicator	Rudder angle indicator – as required by SOLAS V/19 INS (mandatory) – as required by MSC.252(83), clause 7.5.2.1, to be displayed on INS navigation control display.	
			Autopilot settings	Autopilot settings	Autopilot unit INS (mandatory) – as required by MSC.252(83), clause 7.5.2.1, to be displayed on INS navigation control display.	
Change course		See section "Change course using Autopilot/ Hand steering under generic conditions"				
Prepare to change speed	Check the ship's progress in the fairway compared to the plan		Passage plan and the ship's position	The display of own ship position and the route on the ENC	ECDIS	
	Check traffic situation		Known, unknown, and expected traffic	Target echoes and AIS data displayed on Radar Visual observation of traffic situation	Radar	Additional information may be available from VTS
Change speed	See section "Change the ship's speed under generic conditions"					
Avoid collision	See section "Collision avoidance"					
Navigating in open waters						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Monitor the sailing	Plot position	Plot position using suitable methods, considering prevailing conditions				
	Determine necessary course changes if the ship is off course		The ship's position relative to the planned track	The display of own ship position and the route on the ENC	ECDIS	
			Cross track distance value	XTD	Not required, according to performance standards. However, many ECDIS systems have this information displayed to support route monitoring.	
	Monitor course		Course information	HDG	Heading indicator (Gyrocompass) Radar (mandatory) – as required by MSC.192(79), clauses 5.19.3 and 8.1. Data from Heading sensors must be inputted into Radar. ECDIS (mandatory) – as required by MSC.232(82), clause 11.4.8. Data from heading sensors must be inputted into ECDIS. INS (mandatory) – as required by MSC.252(83), clause 7.3.2, to be displayed on INS navigation control display.	
				COG	GNSS unit Radar (mandatory) – as required by MSC.192(79), clause 5.28.6,	

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					among other own ship AIS data. ECDIS (mandatory) – as required by MSC.232(82), Appendix 3, clause 11. INS (mandatory) – as required by MSC.252(83), clause 7.3.2.	
	Monitor speed	Monitor actual speed	Speed through water	Speed log (STW)	Speed log indicator. ECDIS (mandatory) – as required by MSC.232(82), clause 11.4.8 – repeating the indication from speed log.	
			Speed over ground	Position sensors (SOG) Speed log (dual axis doppler log)	GNSS indicator. Speed log indicator (for dual axis doppler log). ECDIS (mandatory) – as required by MSC.232(82), clause 11.4.8 – repeating the indication from speed log or GNSS.	
		Monitor propulsion data	Propulsion data	Propulsion data		
	Monitor external environment	Monitor and determine changes to wind direction and speed	Wind direction and speed			
		Monitor and determine changes to current direction and speed	Set and drift			
		Monitor sea stage	The amount of clutters on radar screens	Radar operational display area		
		Determine visibility	Distance to the furthest visible targets	Visual sighting of targets Echoes of targets on Radar screens VRM		
		Locate rain or snow squalls	Location of rain or snow squalls	Visual sighting of squalls Clutters on Radar screens VRM and EBL		
Change course	Prepare for course change	Check passage plan	The passage plan	The active route displayed on the ENC Route information WP information		
		Check for approaching waypoints	Time and distance to wheel-over	Time and distance to wheel-over		
		Check traffic situation and confirm that the new course is suitable	Known, unknown, and expected traffic	Target echoes and AIS data displayed on Radar Visual observation of traffic situation		
	Change course	See section "Change course using Autopilot/ Hand steering under generic conditions"				
Change speed	See section "Change the ship's speed under generic conditions"					
Avoid collision	See section "Collision avoidance"					
Monitor and adjust bridge equipment	Monitor and adjust Radar settings to ensure optimal performance	Brightness adjustment	Brightness level	Brightness level		
		Change scale	Range scale	Range scale		
		Adjust Gain	Gain level	Gain level		
		Adjust Rain & Sea anti-clutter controls	Rain and Sea anti-clutter settings	Rain and Sea anti-clutter settings		
		Off-centre	Off-centre display function	Off-centre display function		
		Adjust Display Mode	Motion settings	Motion settings		

		Check gyro heading accuracy	Heading information	HDG		
			Course data	COG/CTW		
		Check stabilisation settings	Stabilisation source (Sea/Ground)	Stabilisation source		It is likely that Sea stabilised will be used in open waters since Radars play no part in navigation in open waters

Repeated tasks

Collision avoidance

Monitor traffic situation						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Detect the presence and location of other ships	Detect targets	Determine target's existence	Visual sighting of targets	Visual sighting		Visual sighting is often prioritised in good visibility
			Radar sighting of targets	Echoes of targets displayed on the Radar screens		If visual sighting is unavailable due to poor visibility, Radar echoes is the main source of information for traffic monitoring
			Positions of Target AIS symbols	Target AIS symbols displayed on the Radar screens or ENC		AIS data is not prioritised when monitoring traffic since the reliability of the information depends on whether information was entered correctly to the transmitting stations. Still, it can be used as an additional source of information. AIS target symbols are also useful for small targets in bad weathers with lots of screen clutters.
	Alert/Attention to targets	Determine targets' positions relative to own ship	Targets' relative bearings	Visual sighting/EBL		
			Targets' RNG and BRG	EBL and VRM		
		Determine targets' positions relative to landmark	Visual sighting of targets and landmarks	Visual sighting		Visual sighting is often prioritised in good visibility
			Radar sighting of targets and landmarks	Echoes of targets and landmarks displayed on the Radar screens		If visual sighting is unavailable due to poor visibility, Radar echoes is the main source of information for traffic monitoring
			Positions of Target AIS symbols	Target AIS symbols displayed on the Radar screens or ENC		AIS data is not prioritised when monitoring traffic since the reliability of the information depends on whether information was entered correctly to the transmitting stations. Still, it can be used as an additional source of information. AIS target symbols are also useful for small targets in bad weathers with lots of screen clutters.
		Estimate targets' approximate speed and direction of travel	Target trails	Radar target trails		
Evaluate safety-related factors to filter potential risk of collision	Identify weather factors that affect the movement of vessels in the area		Wind direction and speed			Results from Vu et al. (2019) indicate that seafarers often evaluate wind direction and speed based on visual observation
			Set and drift			
	Safety margin		Minimum required CPA			
Evaluate targets						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Identify targets	Synchronising targets between bridge view and true view	Determine targets' positions relative to own ship	Targets' relative bearing	Visual sighting/EBL		
			Target's RNG and BRG	EBL and VRM		

		Determine targets' positions relative to landmark	Visual sighting of targets and landmarks	Visual sighting		
			Radar sighting of targets and landmarks	Echoes of targets and landmarks displayed on the Radar screens		
			Positions of Target AIS symbols	Target AIS symbols displayed on the Radar screens or ENC		
	Determine targets' identification, navigation status, and expected changes		Target identification, size, type, navigation status, and voyage-related data	Visual sighting of targets (lights, shapes, vessel type and relative size) Target AIS static data (Identification, size, type), navigation status, and voyage-related data (port of call)		
	Mark targets for monitoring			Target acquisition		
Determine targets' position and movement	Monitor targets' position		Target RNG and BRG	Visual sighting/EBL VRM		
	Monitor targets' movement	Plot relative vectors		ARPA		
		Plot true vectors		ARPA		
		Calculate targets' CRS and SPD		ARPA		
Identify risk of collision	Monitor target bearing		Target BRG	Visual sighting/EBL		
	Plot target relative vector		Target relative vector	ARPA		
	Calculate CPA and TCPA		Target CPA/TCPA	ARPA		
	Calculate target CRS and SPD		Target CRS/SPD	ARPA		
	Monitor real time position of own ship		Own ship real time position	The display of own ship position and the active route on the ENC		
	Consult collision-avoidance regulations		COLREGs and special agreements in the areas			
Actions to avoid collision						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Consider actions to avoid collision	Consider environmental constrains to the navigation of own ship		Wind direction and speed			
			Set and Drift			
			Navigable waters in the vicinity, considering the vessel's characteristics	The display of own ship position and the active route on the ENC Chart data including water depth, navigation hazards, AtoN		
			Safety margins	Minimum CPA		
	Consider applicable rules of the road and determine possible course changes	Monitor targets' position	Target RNG and BRG	Visual sighting/EBL VRM		
		Monitor targets' movement	Target relative vectors	ARPA		
			Target and own ship true vectors	ARPA		
			Target CRS and SPD	ARPA		
	Consider course/speed change(s) to evaluate the viability of the new course	Calculate new relative vectors and CPAs for the intended course/speed change(s)	New target relative vectors following the intended course/speed change New target CPA following the intended course/speed change	Trial Manoeuvre		
Execute course and/or speed change	Change course and/or speed		Refer to "Conning"			
Repeat "Monitor traffic situation" step						

Conning

Manoeuvring under generic conditions

Change course using Autopilot/ Hand steering under generic conditions						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Decide whether the course change is to be performed by Autopilot or Hand steering	Consider the vessel's manoeuvring characteristics		Vessel's manoeuvring characteristics			Existing literature contains few details about this consideration. This task should be expanded.
Check current heading and COG	Check current heading		HDG	Compass		
	Check current COG		COG	Position sensor		
Change course and monitor the execution	Change course		Course to steer	Source depends on the operation being performed		If course change is carried out by hand steering, helm orders are given after course to steer is decided
	Confirm that the course change has been initiated	Check rudder angle	Rudder angle	Rudder angle indicator		
		Check Rate of Turn	Rate of Turn	Rate of Turn indicator		
		Check the ship's turning motion	Own ship motion data (transverse speed at bow and stern, etc.)	Speed log		
		Check radar and chart displays to confirm the vessel is turning	Changes to radar echoes Changes to own ship heading line and own ship vector on Radar and ECDIS displays	Radar operational display area Own ship heading line and own ship vector on Radar and ECDIS displays		The vessel's turning motion is also monitored through visual observation and bodily feel of the ship's movement and list through vestibular and body posture senses
	Control the turn	Monitor Rate of Turn	Rate of Turn	Rate of Turn indicator		
		Monitor the ship's motion	Own ship motion data (transverse speed at bow and stern, etc.)	Speed log		
		Check radar and chart displays to confirm the vessel is turning	Changes to radar echoes Changes to own ship heading line and own ship vector on Radar and ECDIS displays	Radar operational display area Own ship heading line and own ship vector on Radar and ECDIS displays		The vessel's turning motion can also be confirmed through visual observation and bodily feel of the ship's movement and list through vestibular and body posture senses
		Monitor the progress of the turn using curved EBL and Predictor functions	Predicted turning trajectory	Curved EBL on Radar		This is not a mandatory function required by IMO performance standards. Nevertheless, many Radar systems provide this feature, using different names. The name "Curved EBL" is used on Furuno radars (Furuno, 2011), JRC (2011) uses the name "Manoeuvre Curve". This function displays a curve predicting the trajectory of the vessel during a turning manoeuvre, starting from the wheel-over point and ending after the turn is finished.
				Predictor on ECDIS		This is not a mandatory function required by IMO performance standards. Nevertheless, many ECDIS systems provide this feature, using different names. The name "Predictor" is used in SIMRAD (2018) systems, while

						Tokyo Keiki (2014) calls it Prediction Line. This function displays a curved vector, predicting the trajectory of the vessel in a turning manoeuvre.
	Check new course	Confirm that the vessel is on course	HDG	Compass		
			COG	Position sensor		
		Check to confirm that Rate of Turn has been decreased	Rate of Turn	Rate of Turn indicator		
		Check rudder indicator for use of counter rudder	Rudder angle	Rudder angle indicator		
		Check radar and chart display to view the vessel's new course and heading	Own ship heading line Own ship vector	Own ship heading line and own ship vector on Radar and ECDIS displays		
Change the ship's speed under generic conditions						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Change and monitor the ship's speed	Prepare to give engine order	Check the ship's speed	SPD	Speed log Position sensor		
		Check the ship's propulsion data	Propulsion data	RPM/pitch indicator		
			Engine order	Engine order telegraph		
	Give engine order		Desired new speed	Source depends on the operation being performed		
	Confirm that a speed change has been initiated	Check to confirm changes to the ship's propulsion data	Propulsion data	RPM/pitch indicator		Changes to the ship's propulsion can also be noticed by listening to engine telegraph sound and ship funnel sound, or by feeling changes to the ship's vibration. Additionally, visual observation of bow/stern wave or visual estimation of speed can also be used.
			Engine order	Engine order telegraph		
	Monitor changes to the ship's speed	Verify actual speed	SPD	Speed log Position sensor		

Precision manoeuvring (performed in constricted waters)

Change course using Autopilot/ Hand steering						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Change course using Autopilot/ Hand steering		See section "Change course using Autopilot/ Hand steering under generic conditions"				
Change the ship's speed		See section "Change the ship's speed under generic conditions"				
Monitor drift			The ship's movement	Radar operational display area Radar parallel index lines Speed log (for speed and motion data) Visual observation of the ship's motion HDG and COG Predictor on ECDIS Own ship position and vector displayed on the ENC		
Monitor speed	Monitor internal factors affecting speed	Check actual speed	SPD	Speed log Position sensor Visual observation of the ship's speed		
		Check propulsion data	Propulsion data	RPM/pitch indicator		
			Engine order	Engine order telegraph		
	Monitor external factors affecting speed	Check wind direction and speed	Wind direction and speed			
		Check current direction and speed	Set and drift			

Plot position

Plot position using GNSS sensors						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Plot position using GNSS sensors			Latitude, Longitude	GNSS sensors		On vessels not carrying paper charts, there is no need for manual plotting. The ship's position is automatically plotted on the ENC continuously. LAT/LON information, therefore, is of not use in such cases.
Plot position manually						
Tasks	**Level 1 sub-tasks**	**Level 2 sub-tasks**	**Required information**	**Source of information**	**Equipment**	**Notes**
Plot position using cross bearings	Identify suitable landmarks for reference		Location and characteristics of landmarks in the vicinity	Visual sighting of landmarks The display of landmarks on the ENC The echoes of landmarks on the Radar screen(s)		
	Measure bearings to selected landmarks		The estimated location of selected landmarks relative to own ship	Visual sighting of landmarks The display of landmarks on the ENC The echoes of landmarks on the Radar screen(s)		
	Record the bearings measured		The measured bearing values of selected landmarks	EBL		
	Plot bearing lines to determine position		The measured bearing values of selected landmarks	EBL Lines of position (LOP)		
Plot position using bearing and distance to one landmark	Identify a suitable landmark for reference		Location and characteristics of landmarks in the vicinity	Visual sighting of landmarks The display of landmarks on the ENC The echoes of landmarks on the Radar screen(s)		
	Measure range and bearing to the selected landmark		Estimated location of the selected landmark relative to own ship	EBL VRM		
	Plot position on the chart		Range and Bearing to the selected landmark	Lines of position		
Verify manually plotted positions	Compare plotted positions with surrounding environment		Manually plotted position	Lines of position		
			Surrounding landmarks	The display of landmarks on the ENC		

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Annex 6 – List of mandatory INS functions

Mandatory functions of Integrated Navigation Systems

This document lists mandatory functions on Integrated Navigation Systems [INS] as required by resolution MSC.252(83) Performance Standards for INS and compares with requirements from resolutions MSC.232(82) Performance Standards for Electronic Chart Display and Information System [ECDIS] and MSC.192(79) Performance Standards for Marine Radar.

Function	**Corresponding INS task group** (there are six INS task groups, listed in MSC.252(83) - 7.1.1)	**Relevant clauses in Resolution MSC.252(83)**	**Relevant clauses in Resolution MSC.232(82)**	**Relevant clauses in Resolution MSC.192(79)**
Mode and status information	Route planning, Route monitoring, Collision avoidance, Navigation status and data display	**7.7.1, 9.3.1**	**5.2**	**5.20.3**
VRM	Route planning, Route monitoring, Collision avoidance	**7.2.1, 7.3.1, 7.4.1**	**11.4.12**	**5.12**
EBL	Route planning, Route monitoring, Collision avoidance	**7.2.1, 7.3.1, 7.4.1**	**11.4.12**	**5.15**
Offset measurement of range and bearing	Route planning, Route monitoring, Collision avoidance	**7.2.1, 7.3.1, 7.4.1**	**11.4.12**	**5.17**
Radar/Chart Overlay	Route monitoring, Collision avoidance	**7.3.2**	**7.1**	**5.33**

The presentation of True scale ship symbol (optional feature)	Route monitoring, Collision avoidance	**7.4.3**	**9.4**	
Range scale display and adjustment	Route monitoring, Collision avoidance	**7.3.1, 7.4.1**	**5.7**	**5.1**
AIS safety related messages	Navigation control data, Status and data display	**7.5.2.1, 7.7.1**		
NAVTEX messages	Navigation control data, Status and data display	**7.5.2.1, 7.7.1**		
Voyage records	Route planning	**7.2.1.**	**11.5**	
The display of own ship's position and the selected route on the chart	Route monitoring	**7.3.1**	**11.4.1**	
The display of Time-labels along a ship's track at selected interval	Route monitoring	**7.3.1**	**11.4.12**	
The display of the Alternative Route	Route monitoring	**7.3.1**	**11.4.11**	
Function to display areas off ship's position (e.g. for looking ahead and planning) and return to own ship's position	Route monitoring	**7.3.1**	**11.4.2**	
SAR and MOB modes	Route monitoring	**7.3.4, 7.3.5**		
Manually adjusting the ship's position	Route monitoring		**11.4.14**	
Cross Track Error (XTE)	Route monitoring	No specific requirements regarding the display of this information. However, MSC.232(82) 11.3.6 requires a functionality for setting up XTE limit and MSC.232(82) 11.4.5 requires a functionality for auto-activating an alarm when the ship exceeds such limit		
Route modifying tools and function to switch from the selected route to an alternative route	Route monitoring	**7.3.1**	**11.4.11**	
Function to find a point by entering coordinates or read the coordinates of a point	Route monitoring	**7.3.1**	**11.4.13**	
Display relevant symbols required for navigation purposes	Route monitoring	**7.3.1**	**11.4.12.2**	

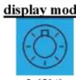
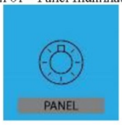
The presentation of Radar and AIS targets	Collision avoidance	**7.4.1**		**5.24.1**
Function to filter AIS targets according to user-defined parameters	Collision avoidance	**7.4.1**		**5.26.1**
Target tracking and acquisition	Collision avoidance	**7.4.1**		**5.25.3, 5.25.4**
Target Information (both tracked and obtained from AIS)	Collision avoidance	**7.4.1**		**5.24.2**
CPA/TCPA	Collision avoidance	**7.4.1**		**5.28.2, 5.28.3**
BCR/BCT	Collision avoidance	**7.4.3**		
Target Trails and Past Positions	Collision avoidance	**7.4.1**		**5.23**
Radar Bearing Scale	Collision avoidance	**7.4.1**		**5.13**
Fixed range rings	Collision avoidance	**7.4.1**		**5.11**
Parallel Index Lines (PI)	Collision avoidance	**7.4.1**		**5.16**
Trial Manoeuvre	Collision avoidance	**7.4.1**		**5.31**
Radar Gain and Anti-Clutter Functions	Collision avoidance	**7.4.1**		**5.3.2**
Radar performance optimization and tuning (automatic/manual tuning)	Collision avoidance	**7.4.1**		**5.7**
Heading Line suppression function	Collision avoidance	**7.4.1**		**5.14.3**
SART and Radar Beacons signal processing function	Collision avoidance	**7.4.1**		**5.3.4.3**
Functions to enhance target presentation on the radar display	Collision avoidance	**7.4.1**		**5.3.3.1**
LAT/LON	Navigation control data	**7.5.2.1**		
HDG, COG, SOG, STW	Navigation control data	**7.5.2.1**		
Rate of Turn (RoT)	Navigation control data	**7.5.2.1**		
Under Keel Clearance (UKC)	Navigation control data	**7.5.2.1**		
Propulsion data	Navigation control data	**7.5.2.1**		
Rudder angle	Navigation control data	**7.5.2.1**		
Time and Distance to wheel-over or the next WP	Navigation control data	**7.5.2.1**		

Set and Drift	Navigation control data	**7.5.2.1**		
Wind direction and speed	Navigation control data	**7.5.2.1**		
The active mode of speed or steering control	Navigation control data	**7.5.2.1**		
Ship's static, dynamic and voyage-related AIS data	Status and data display	**7.7.1**		
Ship's relevant motion data	Status and data display	**7.7.1**		
Sensor and source information	Status and data display	**7.7.1**		
System configuration	Status and data display	**7.7.1**		
Tidal and current data (optional feature)	Status and data display	**7.7.3**		
Weather data (optional feature)	Status and data display	**7.7.3**		
Ice data (optional feature)	Status and data display	**7.7.3**		
Alarms	Alert Management	**7.6.1**		
Cursor readouts	Status and data display	**11.4.12, 5.18**		
Radar Ground and Sea Stabilization Mode	Collision avoidance			**5.22**

Annex 7 – Full results of icon usability tests

G01 – Illumination

This group contains icons representing functions to adjust illumination settings.

Original design	Sources	Comments from users	Interpretation of user feedback: Results	Interpretation of user feedback: Discussion	Suggestions
Icon 01 – Panel Illumination  Icon 02 – Display Brilliance  Icon 36 – Day/ Night/ Dusk display mode 	Survey	Q1 – Which of the following Icons represents the function for setting **Panel Illumination**?    10 (33%) 2 (7%) **18 (60%)** Total 30	Without the aid of captions, both Icon 01 - Panel Illumination and Icon 02 - Display Brilliance failed to represent their intended functions.	The survey results show that, compare to Icon 01 and 02, Icon 36 is closer associated with brightness settings. The reason can be the pictographs used in those three Icons. Icon 36 concretely depicts the sun and the moon. Since both the sun and the moon are associated with the concept of light, when given the context provided in the question, users can easily associate Icon 36 with the adjustment of brightness. This assessment corresponds to the results of survey questions 1 and 6. Both Icon 01 and 02 are existing standard (IEC, 2007). Icon 01 and 02 depict a light bulb and the sun respectively, both of which are related to light. However, both Icons have a circle surrounding the main symbol. Icon 36, on the other hand, does not have this circle. In the interview sessions, one interviewee comment that the symbol for Icon 02 –Display Brilliance was not intuitive enough. Combining these facts, we believe, in the cases of Icon 01 and 02, that the presence of a circle surrounding the main	• Remove the circle surrounding the main symbol in Icon 01 and Icon 02. • The caption for Icon 01 should be "PANEL ILLUMINATION", as in Table I.2 of IEC standard (2014). • The caption for Icon 02 should be "BRILLIANCE" or even "DISPLAY BRILLIANCE". • The caption for Icon 36 should be "DAY/ NIGHT"  
		Q6 – Which of the following Icons represents the function for setting **Display Brilliance**?    9 (21%) 15 (35%) **19 (44%)** Total 43			
		Q55 – Which of the following Icons represents the function to toggle between **Day/ Night/ Dusk display mode**?    2 (5%) 1 (3%) **34 (92%)** Total 37	92% of the participants selected Icon 36 - Day/ Night. This indicates that Icon 36 - Day/ Night is strongly associated with the function to toggle between different modes of brightness.		
	Interview	Icon 01 – Panel Illumination 	Upon seeing the symbol for Icon 01, all interviewees immediately associate it with the control of the brightness level. However, the interviewees were guided toward screen brightness rather than the illumination level for the console panel. The caption "PANEL" used in this Icon was rather counterintuitive and caused confusion to interviewees.		

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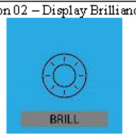
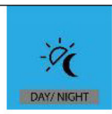
		Icon 02 – Display Brilliance 	All interviewees correctly interpreted this Icon as the function to adjust screen brightness. However, one interviewee commented that the caption "BRILL" could be difficult to interpret and suggested using "BRILLIANCE" instead. Another interviewee comment that, while the label "BRILL" could be ok, the symbol was not intuitive enough.	symbol reduce the Icons' comprehensibility. Furthermore, the abbreviation of Icon captions can cause difficulties for users, as seen in the caption "PANEL" and "BRILL" for Icon 01 and 02. The interviewees tend to associate brightness adjustment with the screen brilliance instead of panel illumination. However, in practice, most system will have the Panel Illumination Icon located on the console panel and the Display Brilliance Icon located on the screens. The location of these Icons can make it easier for user to interpret and the interpretation in reality can be better than the survey results.	
		Icon 36 – Day/ Night/ Dusk display mode 	The interviewees easily recognise the Icon as toggling between Day/ Night/ Dusk display modes.		

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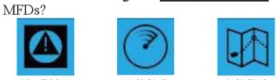
G02 – Multi-function Displays (MFD)

This group contains icons representing display modes for multi-function navigation displays (such as those in Integrated Navigation Systems).

Original design	Sources	Comments from users	Interpretation of user feedback		Suggestions
			Results	Discussion	
Icon 03 – ECDIS 	Survey	Q2 – Which of the following Icons represents the function for selecting the **ECDIS mode** on MFDs?  **27 (90%)** 1 (3%) 2 (7%) Total 30	The two Icons 03 – ECDIS and 04 – Radar are concrete and easy to be interpreted. When combine with the context provided in the question, most users were able to associate the Icons with their intended functions.	Icon 03 – ECDIS and 04 – Radar are very concrete and easily recognisable, even without caption. Icon 05 – Conning and 06 – CAM-HMI are less concrete and more difficult to interpret. The interview sessions show that, without the context of multi-function displays, users could not correctly interpret the Icons in this group. However, once the context of MFD was provided, users could easily recognise the Icons. During the interview sessions, one interviewee argued that the symbol for a chart should not be folded as in the Icon. However, all interviewees were able to recognise the symbol nonetheless. Still, we believe redesigning Icon 03 using the symbol of a flat chart can improve aesthetic value for the Icon and, as a result, improve user experience. Still, such speculation need to be evaluated and since Icon 03 is usable as it is now, we consider redesigning Icon 03 not a priority at the moment.	• Despite the success in the survey results, all Icons in this group must be applied with caution. Many users are not familiar with multi-function displays and, without such context, are unlikely to interpret these Icons correctly. Any implementation must consider making clear to users this contextual information. • Icon 05 – CONNING need to be redesigned. • Icon 06 need to have another caption, using terminologies familiar to seafarers. We suggest using "ALARMS" or "ALL ALARMS".
Icon 04 – RADAR 		Q7 – Which of the following Icons represents the function for selecting the **RADAR mode** on MFDs?  **41 (95%)** 1 (2%) 1 (2%) Total 43			
Icon 05 – CONNING 		Q54 – Which of the following Icons represents the function for selecting the **CONNING mode** on MFDs?  **30 (81%)** 4 (11%) 3 (8%) Total 37	Icon 05 – Conning is more abstract in design compare to Icon 03 – ECDIS and Icon 04 – Radar. However, when combine with the context provided in the question and the additional context supported by other Icons in this question, the majority (80%) of users were able to interpret this Icon correctly.		
Icon 06 – CAM-HMI 		Q59 – Which of the following Icons represents the function for selecting the **CAM-HMI mode** on MFDs?  **19 (70%)** 4 (15%) 4 (15%) Total 27	Icon 06 – CAM-HMI is an arbitrary Icon, meaning that there is no visual connection between this Icon and the concept it represents. The meaning of such Icon is assigned through conventions or standards, and users are usually not able to interpret		

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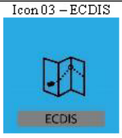
			such Icons without learning them beforehand (Siau, 2005). In this case, the majority (17 – 68%) of the participants correctly interpreted the Icon without prior knowledge. This may happen because the two answer choices in the question - Icons 03 and 04 are very concrete and easy to interpret.	Icon 05 – Conning depicts a rudder indicator in a very abstract manner, which caused great difficulties to interviewees. Still, users are likely to make a correct interpretation when they see the label and other Icons in this group. Standing alone, however, Icon 05 does not make much sense and, therefore, should be modified.	
	Interview	Icon 03 – ECDIS 	All interviewees recognise the symbol of a chart with a passage plotted on it. However, one of the interviewee wondered why the chart was depicted as being folded in the Icon. He suggested that the symbol of a chart should not folded as in this case. Without any additional context, only one interviewee correctly interpreted this Icon as ECDIS Mode. Other four interviewees considered this Route Monitoring or Route Planning. Upon seeing the caption, all interviewees recognised the Icon as a symbol for ECDIS. However, not all of the interviewees were familiar with Multi-function displays. Still, given that the interviewees are able to associate the Icon with ECDIS, if additional context is provided, such as the equipment in which the Icon	Icon 06 – CAM-HMI is an arbitrary Icon. However, since the exclamation mark is widely used across multiple platforms to indicate issues, interviewees easily associated the Icon with the concept of warnings or alarms. Given the context of MFD and other Icons in the group, users can easily make the correct interpretation. On the other hand, the caption CAM-HMI is not familiar to users and all interviewees were confused by the term. It is suggested that a more "nautical" and less "technical" term should be used instead.	

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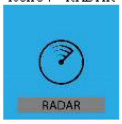
			is used, or other Icons in the group, users can correctly interpret the Icon.		
		Icon 04 – RADAR 	All interviewees recognised the symbol of Radar. However, similar to Icon 03 – ECDIS, without additional context, interviewees could not identify the exact meaning of the Icon. Still, similar to Icon 03, if given additional information about the context, users are likely to correctly identify the meaning of this Icon.		
		Icon 05 – CONNING 	This Icon has a symbol of the rudder indicator. Upon seeing the symbols, two of the interviewees immediately recognised the symbol as Conning. One interviewee interpreted this as Engine Telegraph, and another replied Range Scale. The last interviewee commented that the Icon does not make any sense to him and should be redesigned completely. When being shown the label, all interviewee confirmed the answer to be Conning Mode. The answers of the interviewees show that Icon 05 is not easily interpretable without the caption. This may happen because there are		

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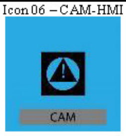
			various designs of rudder indicator in the market. The two interviewees who immediately recognised this Icon as Conning Mode might had encountered rudder indicators of similar design to this Icon before. They could have also been supported by the context of this Icon group and the previous two Icons 03 and 04. The design of this Icon should be modified to better represent the concept of Conning.		
		Icon 06 – CAM-HMI 	This Icon is arbitrary in nature, so it was expected that users would need to be familiar with the Icon before being able to recognise it. Upon seeing the symbol, all interviewees were able to associate the Icon with the concept of warnings. For that reason, if given enough context, WE believe the users will be able to interpret the Icon correctly. The label, however, confused the interviewees. Despite being an official IMO terminology, Central Alert Management Human-machine Interface is very technical term, with which few users are familiar. The interviewees suggested using common "nautical" languages for new terminologies. One		

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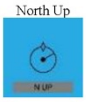
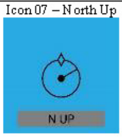
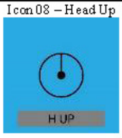
			interviewee proposed the label "ALARM".		

G03 – Display Orientation

This group contains icons representing different display orientation modes

Original design	Sources	Comments from users	Interpretation of user feedback: Results	Interpretation of user feedback: Discussion	Suggestions
Icon 07 – North Up 	Survey	Q3 – Which of the following Icons represents the function for selecting the **North Up** orientation mode?  **19 (63%)**  4 (13%)  7 (23%) Total 30	In question 3, 63% of users correctly interpreted Icon 07 as North Up. In questions 8 and 49, very few users (14% and 0% respectively) associated Icon 07 with Head Up or Course Up.	Results of survey questions 8 and 49 show that Icon 07 is clearly not associated with the concept of Head Up or Course Up. However, as seen in question 3, Icon 07 does not properly represent the concept of North Up either as only 63% of the respondent correctly identified the Icon. Therefore, Icon 07 needs to be improved to depict the North direction better. Both Icons 08 and 09 have a line-shaped symbol pointing upward. The line implies the concept of Heading, and since both lines are pointing upward, users tend to associate both Icons with the concept of Head Up. Results of Q49 in the survey show that, when staying in a group, Icon 09 can be identified by many users (69%) as Course Up. However, the interviews	• Redesign Icon 07 to better represent the northward direction. We propose changing the diamond shape on top of the Icon to the north arrow with a letter "N" above or underneath. • Icon 09 need to be redesigned to better depict the concept of Course and to differentiate with Icon 08.
Icon 08 – Head Up 		Q8 – Which of the following Icons represents the function selecting the **Head Up** orientation mode?  6 (14%)  **20 (47%)**  17 (40%) Total 43	In question 8, similar number of respondents associated the concept of Head Up to both Icons 08 and 09 (47% and 40% respectively). This result shows that both Icons 08 and 09 can be interpreted as Head Up and users were confused between these two Icons.		
Icon 09 – Course Up 		Q49 – Which of the following Icons represents the function selecting the **Course Up** orientation mode?  0 (0%)  9 (31%)  **20 (69%)** Total 29	In question 49, 69% of the respondent correctly interpreted Icon 09 as Course Up while only 31% interpreted Icon 08 as such. This result shows that Icon 09 better represents the concept of Course Up.		

			For that reason, if a user is scanning the display looking for the Course Up mode, he or she is more likely to correctly select Icon 09. However, if a user is looking for the Head Up mode, he or she is likely to be confused between Icon 08 and 09. Therefore, measure must be taken to make these two Icons more distinguishable.	showed that, when standing alone, Icon 09 is not easily comprehensible. Therefore, Icon 09 need to be redesigned to differentiate from Icon 08 but at the same time better represent the Course Up concept.	
	Interview	Icon 07 – North Up 	Without the caption, two of the interviewees easily identified the symbol as North Up. The other three confused this with the ship Heading. With the caption, all interviewees easily identified the Icon as North Up. One of the interviewees commented that he had encountered similar Icons and labels on TRANSAS systems before, making it easy for him to recognise the Icons.		
		Icon 08 – Head Up 	All interviewees correctly identified this symbol as Head Up. However, the respond time was much faster compare to Icon 07 North Up, and given that this Icon was shown immediately following Icon 07, it is assumed that Icon 07 provided additional context and made it easier for interviewees to identify Icon 08.		

		Icon 09 – Course Up  	Without the label, only one of the interviewees was able to identify the symbol as Course Up. Others identified the Icon as True Motion, Heading Line, and Range. This show that the symbol used in this Icon was misleading to users. The dotted line could be interred as depicting motion; the symbol of a dotted arrow pointing upward from a black dot can be interpreted as Heading Line; and the similarity between Icon 09 and the standard Icon 15 – RANGE confused the interviewees. Consequently, interviewees suggested redesigning Icon 09. When being shown the label "C UP", all interviewees were able to identify the Icon as Course Up.		

G04 – Motion Settings

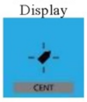
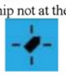
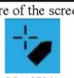
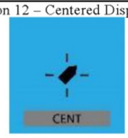
This group contains icons representing motion settings.

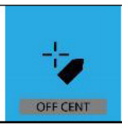
Original desgin	Sources	Comments from users	Interpretation of user feedback		Suggestions
			Results	**Discussion**	
Icon 10 – True Motion TM Icon 11 – Relative Motion RM Icon 14 – True Motion Reset TM R	Survey	Q4 – Which of the following Icons represents the function for selecting the **True Motion** mode? TM: **25 (83%)**; RM: 3 (10%); TM R: 2 (7%) Total 30	Both Icon 10 – True Motion and Icon 11 – Relative Motion are highly comprehensible.	Both Icons 10 – True Motion and 11 - Relative Motion are easy to interpret. In Icon 14, the abbreviation of True Motion Reset as TM R has confused users. Icon 14 need to be redesigned using non-abbreviated words. Additionally, the interviews indicate that many, even experienced, seafarers are not aware of the True Motion Reset function. They are aware of the function to reset the ship's position in True Motion mode, but do not know that the function is called True Motion Reset. No information was provided to identify why people are not aware of this term. Based on personal experience, we believe there are three reasons: • True Motion Reset is activated automatically as the ship get closer to the edge of the screen. Therefore, people may not use this function very often. • Users can manually select the ship's position on the screen using Off-centered	• Icon 14 need to be redesigned, using a more comprehensible label. Using "TM RESET" instead of "TM R" can improve the Icon. Still, if there is another term that is more familiar to users than "True Motion Reset", such term should be used instead. • (*) To determine a better alternative for True Motion Reset, manufacturers can survey seafarers, preferably not native English speakers, to identify the terms they commonly use to refer to this True Motion Reset function.
		Q9 – Which of the following Icons represents the function for selecting the **Relative Motion** mode? TM: 0 (0%); RM: **38 (88%)**; TM R: 5 (12%) Total 43			
		Q50 – Which of the following Icons represents the function of **True Motion Reset**? TM: **14 (48%)**; RM: 3 (10%); TM R: 12 (41%) Total 29	Respondents were difficult to distinguish between Icons 10 – True Motion and 14 – True Motion Reset. However, in Q4, the majority of respondents were able to correctly identify Icon 10 as True Motion. This results show that Icon 14 were not comprehensible and need to be modified.		
	Interview	Icon 10 – True Motion TM Icon 11 – Relative Motion RM	All interviewees easily identified both Icons 10 and 11.		
		Icon 14 – True Motion Reset	Only one interviewee was able to identify Icon 14 as True		

			Motion Reset. The other four interviewees were able to recognise TM as True Motion but were not able to relate the letter R to Reset. They all interpreted this Icon as the function to toggling between True Motion and Relative Motion. Upon learning the meaning of Icon 14, the interviewees commented that the abbreviation of Reset as R in the label caused difficulties to users. They suggested using "Reset" instead of "R" in the label. The interview sessions also showed that many, even experienced, seafarers are not aware of the True Motion Reset function.	Display function, which can substitute the True Motion Reset function. • True Motion Reset is a technical term. Semantically, this term does not describe exactly what the function does. Thus, common users are not likely to be aware of it. Therefore, we suggest substituting it with another "less engineering" but "more nautical" term.	

G05 – Own Ship Location

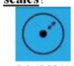
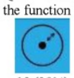
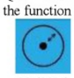
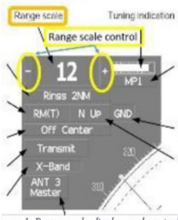
This group contains icons representing different settings for own ship location on the displays.

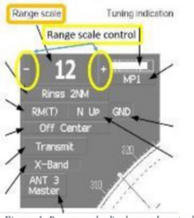
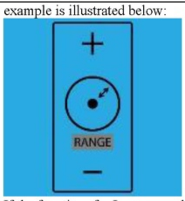
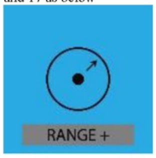
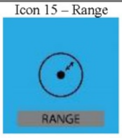
Original design	Sources	Comments from users	Interpretation of user feedback		Suggestions
			Results	Discussion	
Icon 12 – Centered Display  Icon 13 – Off-centered Display 	Survey	Q5 – Which of the following Icons represents the function for **Centered Display** (display the ship at the centre of the screen)?    **22 (73%)** 3 (10%) 5 (17%) Total 30 Q10 – Which of the following Icons represents the function for **Off-centered Display** (display the ship not at the centre of the screen)?    6 (14%) **28 (65%)** 9 (21%) Total 43	In both Q5 and Q10, there are one Icon not belong to this group G05. Despite the presence of an Icon from external groups, both Icons 12 and 13 perform well in the survey (with 73% and 65% correct interpretation respectively). In practice, if Icons 12 and 13 are presented together in a separated Icon group, the results can be even higher. Therefore, Icons 12 and 13 do not need to be redesigned.	Icon 12 and 13 performed well. Still, both Icons can benefit from using labels with non-abbreviated words.	• Change the caption for Icon 12 to "Centered Display" or "Ship Centered". • Change the caption for Icon 13 to "Ship Off-centered" or "Off-centered Display".
	Interview	Icon 12 – Centered Display 	Upon seeing the symbol for Icon 12, three interviewees immediately recognised the Icon as Ship Centered display. One interviewee was confused by the label "CENT". The interviewees referred to this Icon using the following terms "Centered Display", "Centered Display Mode", and "Ship Centered". Based on this result, the label for Icon 12 should be modified.		
		Icon 13 – Off-centered Display	All interviewees easily recognised this Icon as Off-centered display.		

G06 – Range Settings

This group contains icons representing different range settings.

Original design	Sources	Comments from users	Interpretation of user feedback		Suggestions
			Results	Discussion	
Icon 15 – Range  Icon 16 – Increase Range Scale  Icon 17 – Decrease Range Scale 	Survey	Q11 – Which of the following Icons represents the function for seeing all available **Range scales**?    **26 (90%)** 1 (3%) 2 (7%) Total 29 Q16 – Which of the following Icons represents the function for **Increasing the Range scale**?    13 (38%) **20 (59%)** 1 (3%) Total 34 Q45 – Which of the following Icons represents the function for **Decreasing the Range scale**?    13 (29%) 1 (2%) **31 (69%)** Total 45	When comparing to Icons of other groups, Icon 15 – Range was highly distinguishable. However, when placing together other Icons in this group, users are likely to confuse between Icons 15 and 16, as well as 15 and 17. Icon 16 and 17, however, are highly distinguishable. The reason for this confusion could be the design of this Icon group. These three Icons are not consistent in design style, despite referring to the same function of adjusting range scale. Icons 16 and 17 have the same design style, which differs from that of Icon 15. The symbol of a double-headed arrow in Icon 15 can be connected to the concept of "Expanding", which can confuse users with Icon 16 – Increase Range Scale. Additionally, the double-headed arrow in Icon 15 can also be interpreted as "Adjustment", which can potentially be confused with Icon 17 – Decrease Range Scale. This interpretation, however, is less obvious than	Icon 15 – Range is currently the standard Icon prescribed in table I.2 of IEC 62388 (IEC, 2007), while Icons 16 and 17 are not. (*) *The research team mistakenly interpreted Icon 15 as the function to indicate all available Range scales while in fact, it is the symbol used to identify the Range selection switch (the hard key on the console panel for adjusting range scale). This mistake only affected question 11. Fortunately, in question 11, Icon 15 – Range is shown with Icon 40 – Gain and 41 – Tune, both of which belong to another Icon group. As a result, this mistake did not affect the results of this study.* The current design of Icons 15, 16, and 17 poses the following issues: • Users could distinguish between Icons 16 and 17, but were confused between Icons 15 and 16, and 15 and 17. • Icons 16 and 17 are not intuitive and need to be redesigned. To suggest improvements for this Icon group, the research team review the presentation of range control functions currently in use in existing navigation systems.	• Use no Icon for Range control functions on the graphical interface. Instead, we recommend using the presentation illustrated in figure 1 (represented below) to follow universal design among manufacturers:  *Figure 1. Range scale display and control functions on the graphical interface* • For hard keys on operator panel, if the functions for Increase Range and Decrease Range are combined into one hard key as in the case of the Synapsis Radar by Raytheon Anschutz illustrated in Figure 2, we recommend using Icon 15 with the label "RANGE" and the sign "+" and "-". An

			the concept of "Expanding" discussed above. As a result, users would be less likely to confuse between Icons 15 and 16 than between Icons 15 and 17, as seen in the survey results. A comment from survey respondents indicated the use of the terms "Range Up" and "Range Down" could be confusing. The users suggested using the signs "+" and "-" instead.	In most existing radar models, users can change the range scale using two methods: clicking on the soft keys on the graphical interface, or pressing the hard keys on the control panel. On the graphical interface, the range scale currently in use is usually displayed in number, with plus and minus signs on each sides, as seen in the example below from radar model JMA-9100 (JRC, 2011):  *Figure 1. Range scale display and control functions on the graphical interface* Users adjust range scale by clicking the plus and minus signs (the range scale controls). Alternatively, users can also adjust range scale using the control keys on the operator panel, as seen in the example below from radar the Synapsis Radar (Raytheon Anschutz, 2014):	example is illustrated below:  • If the functions for Increase and Decrease Range are presented in two hard keys on the operational panel, we recommend redesign Icons 16 and 17 as below  
	Interview	Icon 15 – Range  	Upon viewing the symbol, only one interviewee was able to recognise the Range function. However, he commented that the symbol could also be interpreted as Variable Range Marker. All other four interviewees interpreted this symbol as Variable Range Marker. When being shown the Icon label, all participants were able to identify the Icon as Range Scale. The two-headed arrow in this Icon can be related to the concept of distance measurement. Additionally, the circle surrounding the Icon is similar to the Variable Range Marker. As a result, this Icon design can be easily interpreted as Variable Range Marker. For the reasons above, this Icon need to be modified.		

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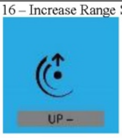
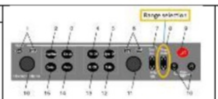
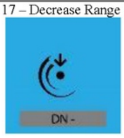
		Icon 16 – Increase Range Scale  	Two of the five interviewees were able to identify this Icon as Increase Range Scale. One replied Course Up, and two were not able to assign a meaning to this Icon. Upon seeing the label, all participants were able to interpret the Icon as Increase Range Scale. Still, participants commented that the Icon design was not intuitive. One participant suggested using the same symbol for Range, only adding the sign "+" to indicate increasing range scale.	 *Figure 2. Range scale control functions on the operator panel* The range selection keys can be placed together in a single control key as presented above, or separately in two control keys "RANGE UP" and "RANGE DN" in certain radar models. Two principles of usable designs are maintaining consistency and simplicity (Nielsen, 1995), which is also the purposes of S-mode. Applying these two principles to the design of this Icon groups, we need a simple, common design style and labels for Icons 15, 16, and 17. The presentation of range scale control functions on the graphical interface as illustrated in figure 1 above has become universal across manufacturers and, as seen through users' feedback, has been well received. Any Icon, if used, should follow the same design language. For this reason, we suggest the improvements as presented in the "Suggestion" section in the next column.	
		Icon 17 – Decrease Range Scale  	Although all five interviewees were able to identify this Icon as Decrease Range Scale, they made the following comments: • The label "DN-" was not intuitive. It will be better using "DECREASE", or a simple sign "-". • Not all three Icons in this group is necessary. The use of Icons 16 and 17 would make Icon 15 redundant and vice versa. Additionally, Icon 15 is more intuitive than Icons 16 and 17. Therefore, the interviewees suggested removing Icons 16 and 17, and use Icon 15 with the sign "+" or "-" instead.		

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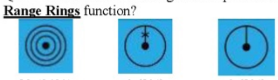
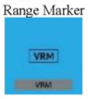
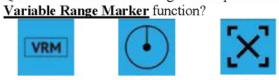
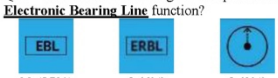
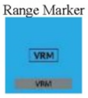
G07 – Navigation Function

This group contains icons representing generic navigation features.

Original design	Sources	Comments from users	Interpretation of user feedback		Suggestions
			Results	Discussion	
Icon 18 – Heading Line Off 	Survey	Q12 – Which of the following Icons represents the function for turning the **Heading Line Off**?  **25 (86%)** 1 (3%) 3 (10%) Total 29	Icons 18 – Heading Line Off, 19 – Range Rings, 20 – Variable Range Marker, and 21 – Electronic Bearing Line performed very well in the survey.	Icons 18 – Heading Line Off, 19 – Range Rings, 20 – Variable Range Marker, and 21 – Electronic Bearing Line are comprehensible. **[Icon 22 – Electronic Range and Bearing Line]** Icon 22 did not perform well in both the survey and the interview sessions. The results of survey question 44 indicate that users were confused between Icon 22 and Icon 08 – Head Up from group G03. This might have occurred due to the design of Icon 08, where the symbol of a line pointing upward resemble a bearing line, and the circle can be interpreted as a variable range marker. This result also suggests that many users might not be familiar with the abbreviation "ERBL". During the interview sessions, among the interviewees who were not able to recognise this icon, there was one case that both the interviewee and interviewer (both of which are master mariners) did not know the function Electronic Range and Bearing Line.	• Keep the current design of Icons 18 – Heading Line Off, 19 - Range Rings, 20 - Variable Range Marker, and 21 – Electronic Bearing Line. • Icon 22 – Electronic Range and Bearing Line does not need to be modified, but should always be placed in the same group with Icons 20 – VRM and 21 – EBL. • Icon 35 need to be redesigned, using the label "Trial" as the icon itself.
Icon 19 – Range Rings 		Q17 – Which of the following Icons represents the **Range Rings** function?  **32 (94%)** 1 (3%) 1 (3%) Total 34			
Icon 20 – Variable Range Marker 		Q13 – Which of the following Icons represents the **Variable Range Marker** function?  **28 (97%)** 0 (0%) 1 (3%) Total 29			
		Q18 – Which of the following Icons represents the **Electronic Bearing Line** function?  **29 (85%)** 2 (6%) 3 (9%) Total 34			
Icon 20 – Variable Range Marker 		Q44 – Which of the following Icons represents the **Electronic Range and Bearing Line** function?  **28 (62%)** 15 (33%) 2 (4%)	Users were confused between Icon 22 and Icon 08 – Head Up from group G03.		

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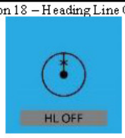
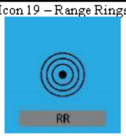
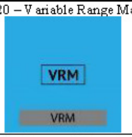
Icon 21 – Electronic Bearing Line 		Total 45		Interestingly, one of the two interviewees who recognised this icon did comment that Electronic Range and Bearing Line is only available on older systems. These facts also suggested that many seafarers might not be familiar with the ERBL function. The Radar performance standards do not specifically require the availability of ERBL, but still provide a definition of ERBL as "*Electronic bearing line carrying a marker, which is combined with the range marker, used to measure range and bearing from own ship or between two objects*" (IMO, 2004, p. 28) The research team attempted to review a number of popular radar models on the market and found that the ERBL function is available on the MDC-2900 series radar by Koden, which is not an old model (Koden Electronics, 2011). Still, since it was not possible for the research team to review all radar models on the market, we could not confirm whether the ERBL function is widely available or not.	
Icon 22 – Electronic Range and Bearing Line 		Q37 – Which of the following Icons represents the function to execute a **Trial Manoeuvre**?  **25 (74%)** 9 (26%) 0 (0%) Total 34	The result of question 37 shows that users can potentially confused between Icons 35 – Trial and 03 – ECDIS mode for MFD from group G02. To prevent such confusion, it is suggested that Icon 35 be modified.		
Icon 35 – Trial Manoeuvre 	Interview	Icon 18 – Heading Line Off 	Two interviewees recognised the symbol of this Icon as Heading Line Off. The other three were not able to interpret the symbol but recognised the label as Heading Line Off. Still, all interviewees agreed that the design of this Icon is logical.		
		Icon 19 – Range Rings 	Four interviewees recognised the symbol of this Icon as Range Rings. One interviewee was not able to interpret the symbol, but recognised the label as Range Rings. Still, all interviewees agreed that the design of this Icon is logical.		
		Icon 20 – Variable Range Marker 	All interviewees correctly interpreted Icons 20 and 21 with ease.		
		Icon 21 – Electronic Bearing Line			

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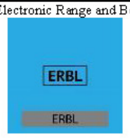
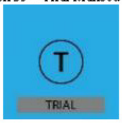
		 		Nevertheless, one interviewee commented that if ERBL were placed next to EBL and VRM, users would likely be able to recognise the function, to which we agree.	
		Icon 22 – Electronic Range and Bearing Line  	Two of the interviewees recognised this icon as Electronic Range and Bearing Line. The other three were not able to recognise this icon. Among the interviewees who were not able to recognise this icon, there was one case that both the interviewee and interviewer (both of which are master mariners) did not know the function Electronic Range and Bearing Line. Interestingly, one of the two interviewees who recognised this icon did comment that Electronic Range and Bearing Line is only available on older systems. These facts suggested that many seafarers might not be familiar with the ERBL function.	**[Icon 35 – Trial Manoeuvre]** In its original design, Icon 35 – Trial Manoeuvre depict the letter "T", which is the abbreviation for Trial Manoeuvre. Icon 03 (ECDIS Mode for MFD) was purposely included in question 37 since it depicts a chart, a ship, and a route, which can be connected to the concept of Manoeuver or Navigation. The result of question 37 shows that users can potentially confused between Icons 35 – Trial and 03 – ECDIS mode for MFD from group G02. Since it is unlikely that Icons 35 and 03 would be located close together in practice, this confusion is unlikely to occur.	
		Icon 35 – Trial Manoeuvre  	Only one interviewee recognised the letter "T" as the abbreviation for Trial Manoeuvre. However, upon being shown the label, all interviewees recognised "Trial" as Trial Manoeuvre.	However, the survey result indicate that the letter "T" in Icon 35 is not easily interpreted as an abbreviation for Trial Manoeuvre, and users can be confused if there is an icon similar to Icon 03 placed near Icon 35 on the interface. This result corresponds to results from the interview sessions.	

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				For this reason, it is suggested that this icon be modified, changing from the letter "T" to "Trial".	

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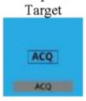
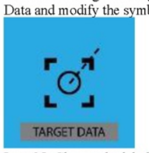
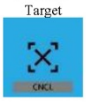
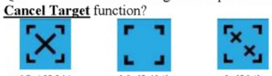
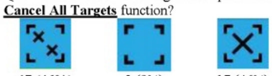
G08 – Target

This group contains icons representing target-related features.

Original design	Sources	Comments from users	Interpretation of user feedback: Results	Interpretation of user feedback: Discussion	Suggestions
Icon 23 – Acquire Target 	Survey	Q14 – Which of the following Icons represents the function for **Target Acquisition**?  **19 (66%)** 9 (31%) 1 (3%) Total 29	The results of questions 14 and 19 show that user confuse between Icons 23 – Acquire Target and 24 – Select Target.	**[Icons 23 – Acquire Target and 24 – Select Target]** Users were confused between the two Icons 23 – Acquire Target and 24 – Select Target. The answers collected during the interview sessions indicate that this confusion may originate from the way seafarers perceive the two functions Target Acquisition and Target Selection. From the technical viewpoint, the action of acquiring a target initiate the tracking of that target. After information about the target has been calculated with ARPA, users can select that target to read target data. As such, Target Acquisition and Target Selection are two distinct functions, the former of which must be performed before the later can be available. On the other hand, from a user's perspective, both functions Acquire Target and Select Target involve moving the cursor over a target and click. Both functions are steps in the process of target monitoring, which serves the overall task of collision	• Icon 23: Change the term from Acquire Target to Target Tracking. Redesign the symbol to better depict the concepts of Target and Tracking.  • Icon 24: Change the term from Select Target to Target Data and modify the symbol.  • Icon 25: Change the label and the term from Pick Report to Info. • Icon 26: Modify symbol to better depict the concept of Cancel but also maintain
Icon 24 – Select Target 		Q19 – Which of the following Icons represents the function for **Target Selection**?  **20 (59%)** 3 (9%) 11 (32%) Total 34			
Icon 25 – Pick Report 		Q43 – Which of the following Icons represents the **Pick Report** function? (Cursor pick on an object to obtaining additional information)  **38 (84%)** 3 (7%) 4 (9%) Total 45	Icon 25 – Pick Report performed well in the survey.		
Icon 26 – Cancel a Target 		Q48 – Which of the following Icons represents the **Cancel Target** function?  **18 (62%)** 10 (34%) 1 (3%) Total 29	Users confused between the Icons for Select Target, Cancel a Single Target, and Cancel All Targets. Especially between Cancel a Single and Cancel All Targets.		
		Q53 – Which of the following Icons represents the **Cancel All Targets** function?  **17 (46%)** 3 (8%) 17 (46%)	Users commented that none of the Icons in this group was intuitive enough, and Icon 24 should be Deselect since it depicts a shape of an empty box. There was, however, one		

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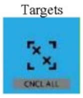
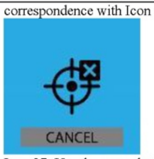
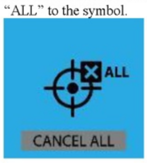
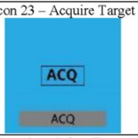
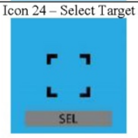
Original design	Sources	Comments from users	Results	Discussion	Suggestions
Icon 27 – Cancel All Targets 		Total 37	comment complimenting Icon 27 – Cancel All Targets to be well designed.	avoidance. However, collision avoidance, just like any other navigation task, also includes numerous other activities, all of which are performed in a cycle "*with no unambiguous beginning or end. Each step depends on a previous step and feeds subsequent steps*" (Hutchins, 1995, p. 133). As a result, the navigators are unlikely to see Target Acquisition and Target Selection as two independent functions but rather merge them together into one continuous process. This explains the results of questions 14 and 19 in the survey. Additionally, the blurry boundary between Target Acquisition and Target Selection in a navigator's perspective can also be seen in the answers of the participants in the interview sessions. When being shown Icon 24 – Target Selections, the following answers were recorded: "*… AIS Acquire?*" (Capt. B) "*Probably … what we have acquired … it stays over there … around the target … it is still the process of acquiring*" (Capt. R) "*That's probably … I don't know … The window or the margin that you want to acquire … I don't know*" (Capt. S)	correspondence with Icon 23.  • Icon 27: Use the same design as Icon 26 but add the word "ALL" to the symbol. 
	Interview	Icon 23 – Acquire Target 	Four interviewees recognised the Icon as Acquire Target.		
		Icon 24 – Select Target 	The symbol used in this Icon is also the standard symbol used to indicate a target that has been selected for data display (IMO, 2014). Three of the interviewees correctly interpreted the icon as Target Selection. The other two interviewees recognised this as the symbol to indicate a target status, but they failed to identify such status as "targets being selected for data readout". All interviewees recognised the label for this icon as an abbreviation of "Select". However, they suggested using the label "Select Target" to make the Icon easier to interpret.		
		Icon 25 – Pick Report 	Four interviewees recognised the meaning of this icon. However, they all commented that the term "Pick Report" is confusing and suggested using the term "Info" or "Information" instead.		

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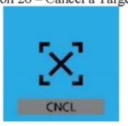
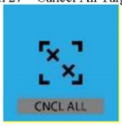
		Icon 26 – Cancel a Target 	Four interviewees recognised the symbol as Cancel a Target. The fifth interviewee recognised the icon after being shown the label.	Since Target Acquisition and Target Selection are two distinct and sequential actions, and many users confused between those two, both Icons must be redesigned. To be usable, both Icons 23 and 24 must depict the process of target monitoring, yet they must be distinct enough to signify their different meanings. It is important to note that the essence of Target Acquisition is the initiation of tracking a target, not the acquisition itself. Similarly, the essence of Target Selection is the data of that target, not the selecting action. For this reason, we recommend using the labels “Target Tracking” for Icon 23 and “Target Data” for Icon 24. Correspondingly, the pictogram used for Icon 23 should depict the concepts of Target and Tracking; the pictogram used for Icon 24 should depict the concepts of Target and Data. [**Icon 25 – Pick Report**] The label for this icon need to be changed to “Info” or “Information” [**Icons 26 – Cancel a Target and 27 – Cancel All Targets**] Both icons performed poorly and many users confused between these two. Icon 26	
		Icon 27 – Cancel All Targets 	Three interviewees recognised the symbol as Cancel All Targets. However, since this Icon is shown immediately after Icon 26 – Cancel a Target, the interviewees had additional context to make the interpretation. One other interviewee guessed this as cancelling multiple targets. He also suggested including the word “ALL” in the symbol to make this icon easier to interpret.		

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				itself is not easily comprehensible. Therefore, both icons need to be redesigned. The feedback of a survey participant on Icon 26 shows that the “X” sign was not interpreted as Cancel but Enter instead. For this reason, we need another sign to better depict the concept of Cancel. The symbol for Icon 26 should also correspondence with Icon 23 since both are connected to target tracking. Icon 27 should follow the same design style of Icon 26, only with additional element to depict the concept All. We suggest using the same design as Icon 26, but include the word “ALL” in the symbol.	

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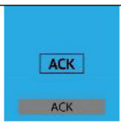
G09 – Alerts and Records

This group contains icons representing alert management and record functions.

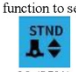
Original design	Sources	Comments from users	Interpretation of user feedback: Results	Interpretation of user feedback: Discussion	Suggestions
Icon 28 - Acknowledge  Icon 29 – Silence Alerts  Icon 30 – Record Events 	Survey	Q15 – Which of the following Icons represents the function to **Acknowledge Alerts**?    **22 (76%)** 7 (24%) 0 (0%) Total 29 Q20 – Which of the following Icons represents the function to **Silence Alerts**?    **26 (76%)** 8 (24%) 0 (0%) Total 34 Q32 – Which of the following Icons represents the function to manually **Record Events**?    **27 (73%)** 7 (19%) 3 (8%) Total 37	Both Icon 28 – Acknowledge Alerts and Icon 29 – Silence Alerts performed well in the survey. However, it is noted that the same pattern of responses was noticed in both questions 15 and 20. No respondent selected the Icon from the external group (Icon 35 – Trial Manoeuvre), this mean that both Icons 28 and 29 are strongly associated with the control of alerts. Between Icon 28 and 29, 76% selected the correct Icon in both questions 15 and 20. This means that 24% of the respondents were confused between Icons 28 and 29. This confusion might not occur because of the Icon design but rather because of the similarity between the two functions. Icon 30 – Record Events performed well in the survey	Most users could recognise Icon 28 as Acknowledge Alerts. However, the abbreviation of “Acknowledge” into “ACK” can potentially confuse users. Therefore, the caption should not be abbreviated. Most users could recognise Icon 29 as Silence Alerts. However, users commented that the abbreviation of “Silence” into “SIL” was not intuitive. In addition, users suggested using the term Mute instead of Silence. Most users could recognise Icon 30 as Record Events. However, they commented that the term “Record” is not common among seafarers and proposed using the term “Log” instead. (*) Although not directly related to S-mode, the survey and interviews reveal additional information on the way seafarers manage alerts in practice: • The results of the survey and the interviews show that, in a seafarer’s perception, Acknowledge	• For Icon 28, change ACK to ACKNOWLEDGE or ACKNOWLEDGE ALERTS or an equivalent abbreviation. • For Icon 29, change the label from SIL to SILENCE, or SILENCE ALERTS, or MUTE, or MUTE ALERTS. • For Icon 30, change the label to LOG EVENT • (*) (*This suggestion is not directly relevant to S-mode but rather to usability of navigation systems*): Conduct studies on bridge alert management, particularly on the use of the two functions Acknowledge Alerts and Silence Alerts. Study the common terms and concepts used by seafarers in practice and consider substituting the “technical” terms used in official document with more “nautical” terms.
	Interview	Icon 28 - Acknowledge	The Icon was obvious to three of the interviewees. However,		

			the Icon can still be confusing for some users since one of interviewees confused it with Acquire Target. This happened because the abbreviation of Acknowledge to ACK is similar to the abbreviation of Acquire Target to ACQ. Additionally, one interviewee interpreted the Icon as Muting an alert. This result indicates that this function can potentially be confused with Silencing Alerts.	Alerts and Silence Alerts are similar since both functions act to mute the alerts. However, these two functions are very different from each other and cannot be used interchangeably. Confusing between these two functions can lead to serious consequences. To take, for example, a hypothetical scenario: *an alarm activated on the bridge while the officer of the watch is engaging in another more important task. He/she decides to temporarily silence the alarm to finish the task at hand, intending to attend to the alerted issue afterward. However, he/she mistakenly uses the Acknowledge Alerts instead of the Silence Alerts function. Consequently, the audible signal for that particular alarm is permanently switched off. The visual alarm announcement is not visible enough to attract the officer’s attention and, consequently, the officer forgets about the alarm until the situation evolves out of control.* While there is no clear evidence in this study to confirm that seafarers actually use these two functions interchangeably in practice, it is worth investigating further into this matter in	
		Icon 29 – Silence Alerts 	All interviewees were able to recognise this Icon as silencing alerts. However, the interviewees referred to this function using the same terms they used to refer to Alert Acknowledgement, such as “Buzzer Off”, “Mute”, and “Cancel Alarm”. This result further indicates that seafarers perceive the two functions Acknowledge Alerts and Silence Alerts similarly. Additionally, the interviewees commented that the Icon caption was not sufficiently comprehensible. The interviewees suggested that Mute would be a more intuitive term than Silence. In addition, they commented that, should the term “Silence” remain being used, it should not be abbreviated and written fully as “SILENCE” or even		

			“SILENCE ALERTS” in the caption.	subsequent studies. If seafarers can confuse between these two functions, changes must be made to improve alert management. • Official IMO documents use the term “Alert” as the umbrella term for all notices of abnormal situations, which include emergency alarms, alarms, warnings, and cautions (IMO, 2010). However, in the interview sessions, all interviewees used the term “Alarm” instead of “Alert”. We suggest the terms and definitions used in alert management. (It should be noted that all interviewees were not native English speaker and so do the majority of seafarers in the industry.)	
		Icon 30 – Record Events 	Two of the interviewees were able to connect the Icon with recording information. The other three replied Route Planning or Typing in additional information. When being shown the caption, all interviewees were able to identify the Icon as Record Events. However, they commented that “Record” is not a good term for seafarers and suggested using the term “Log” instead.		

G10 – System Settings

This group contains icons representing functions to manage different system setting profiles.

Original design	Sources	Comments from users	Interpretation of user feedback		Suggestions
			Results	Discussion	
Icon 31 - Standard Configuration 	Survey	Q21 – Which of the following Icons represents the function to reset the system back to **Standard Configuration**?    **29 (76%)** 5 (13%) 4 (11%) Total 38	The results of questions 21 and 26 show that Icon 31 is highly distinguishable from Icons 32 and 33. The results of question 33 show that users can be confused between Icons 32 and 33.	**[Icons 31, 32, and 33]** The symbol of a gear used in these three icons did not successfully communicate the message of “Configuration”. For this reason, we require another symbol to deliver this concept. The abbreviation of Standard as “STND” in Icons 31 confused users with “Standby”. Additionally, the abbreviation of Configuration as “CONF” in Icon 31 was difficult for users to interpret. Thus, we need a new label for Icon 31. We recommend using the term “Default” instead of “Standard”. The label for Icon 32 and 33 should also be changed to maintain consistency. **[Icon 34 – Standard Display]** This Icon need to be redesigned completely. The symbol for this Icon must deliver the concepts of “Chart” or “ECDIS” and “Standard”. **(*) Notes on the terms Configuration and Setting**	• Change the symbol of a gear in Icons 31, 32, and 33 to another symbol, which better represents the concept of “Configuration”. • Change the label for Icon 31 to “Default Configuration”. If it is necessary to abbreviate, we recommend the abbreviation “Default Config”. • Change the label for Icon 32 to “User Configuration” or “User Config”. • Change the label for Icon 33 to “Save Config”. • Change the symbol for Icon 34 to better depict the concepts of “Chart” or “ECDIS” and “Standard”.
Icon 32 – User Configuration 		Q26 – Which of the following Icons represents the function to select **User Configuration** for system settings?    5 (15%) **26 (76%)** 3 (9%) Total 34			
Icon 33 – Save User Configuration 		Q33 – Which of the following Icons represents the function to **Save Use Configuration**?    0 (0%) 13 (35%) **24 (65%)** Total 37			
Icon 34 – Standard Display		Q38 – Which of the following Icons represents the function to select **Standard Chart Display**?    **29 (85%)** 1 (3%) 4 (12%) Total 34	The results of question 38 show that Icon 34 is highly distinguishable.		
	Interview	Icon 31 - Standard Configuration	None of the interviewee were able to interpret the symbol of a gear as Configuration. Three interviewees correctly interpreted “STND” as		

			Standard, while the other two mistaken it with Standby. Upon seeing the label, only two of the interviewees were able to recognise "CONF" as the abbreviation for Configuration. As a result, this Icon need to be redesign completely, with a new symbol and label.	We notice that in the current draft of the S-mode guidelines, the term Configuration is used to refer to an arrangement of all adjustable system parameters, while the selected value for a specific parameter is known as the setting for that parameter. In other words, a configuration is a unique selection of system parameters, known as settings. Although we cannot find an official definition of Configuration and Setting, the use of these terms in the current draft of the S-mode guidelines corresponds to other technical document in the industry. For this reason, we recommend following the same approach for the icon labels.	
		Icon 32 – User Configuration 	All interviewees correctly interpreted this Icon as User Configuration. However, since this Icon was shown directly after Icon 31, it was likely that the context provided by Icon 31 helped the interviewees recognise this Icon.		
		Icon 33 – Save User Configuration 	All interviewees correctly interpreted this Icon as Save User Configuration. Still, similar to Icon 32, it was likely that the interviewees recognised this Icon based on the context provided by Icons 31 and 32. One interviewee commented that the symbol of a gear Icons 31, 32, and 33 was poorly designed and did not successfully communicate the message of "Configuration".		
		Icon 34 – Standard Display	The interviewees recognised "STND" as the abbreviation for Standard. However, none of them was able to interpret this icon as Standard Display for charts. They all commented		

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		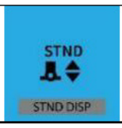	that the symbol was not related to the concept of chart display. For this reason, this Icon need to be redesigned completely.		

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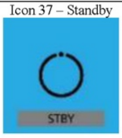
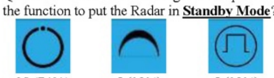
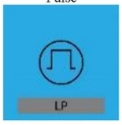
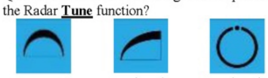
G11 – Radar Control

This group contains icons representing radar controls.

Original design	Sources	Comments from users	Interpretation of user feedback		Suggestions
			Results	Discussion	
Icon 37 – Standby 	Survey	Q22 – Which of the following Icons represents the function to put the Radar in **Standby Mode**?  **28 (74%)** 5 (13%) 5 (13%) Total 38	74% of the respondents correctly selected Icon 37 as Standby. This result means that Icon 37 is distinguishable from other icons in this group. Still, the feedback showed that, on its own, Icon 37 does not represent the concept of Standby Mode very well. Users commented that the symbol is similar to the Power symbol used on many electronic systems.	**[Icon 37 – Standby]** The results of both the survey and the interviews show that users easily confuse this Icon with the Power On/Off function. The symbol used on this Icon is a simplified version of the standard symbol for Standby as prescribed in IEC 60417 (IEC, 2002), such symbol has been widely used to represent the Power button on many electronic devices such as TV remotes or mobile phones. This explains the results of the survey and the interviews. As a result, we need another symbol for this Icon to avoid ambiguity. We have suggested an alternative design in the Suggestion section in the next column. However, it is noted that this new design might be confused with the function to put AIS targets to sleep and should be tested before using. We reviewed a number of radar systems on the market and did not find any model	• Change the symbol for Icon 37 to avoid confusing with the Power On/Off function. We suggest using the Icon below, but it must be tested before application. An alternative is using the caption "STBY" or "STBY TX" as the icon itself.  • Icons 38 and 39 need to be modified to emphasise the difference in pulse length. Additionally, all Icons for pulse length settings must be placed next to each other. • Using full words instead of abbreviations on the labels for Icons 38 and 39. • On the graphical interface, we do not recommend using Icons for Tuning and Gain control. The captions "Tune" and "Gain" can be more effective and, in fact, have already been applied in many Radar models. On the console, the two Icons 40 and 41 should be
Icon 38 – Short Pulse 		Q27 – Which of the following Icons represents the function to select **Short Pulse** on Radar?  **27 (79%)** 3 (9%) 4 (12%) Total 34	It appeared that users might confuse between Icon 38 – Short Pulse and 39 – Long Pulse. The feedback suggested that the symbols for these two Icons were not different enough to draw a distinction.		
Icon 39 – Long Pulse 		Q34 – Which of the following Icons represents the function to select **Long Pulse** on Radar?  8 (22%) 3 (8%) **26 (70%)** Total 37			
Icon 40 – Tune		Q39 – Which of the following Icons represents the Radar **Tune** function?  **13 (38%)** 11 (32%) 10 (29%) Total 34	The results of questions 39 and 42 show that Icon 41 – Gain performed well in representing the concept of Gain control. Icon 40 – Tune, on the other hand, performed poorly and did not explicitly		

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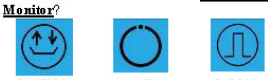
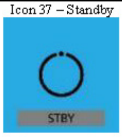
		Q42 – Which of the following Icons represents the Radar **Gain** function?  6 (13%) **34 (76%)** 5 (11%) Total 45	communicate the message of Tuning control.	using the current symbol of Icon 37 to represent the Standby Mode. All of them use the caption "STBY" or "STBY TX" to represent this function. Therefore, an alternative design for Icon 37 is using the caption "STBY" or "STBY TX" as the icon itself. **[Icons 38 – Short Pulse and 39 – Long Pulse]** These two Icons need to be modified to emphasise the difference in pulse length. The letter for pulse length in the label should not be abbreviated to avoid confusion with Radar frequency band. For e.g. "Short Pulse", if abbreviation is necessary, should be "Short P" instead of SP. All Icons representing pulse length settings should be placed next to each other. **[Icon 40 – Tune and 41 – Gain]** Icons 40 and 41 depict the turning of a physical knob to adjust Tuning and Gain control. However, since the Icons were shown without a knob, it was difficult for users to recognise. On most existing Radar models, Tune and Gain can	modified to be less abstract. • Icon 42 – Rain should be modified to be less abstract. • Icon 43 – Sea can keep the current design. • Icon 44 – Performance Monitor should use a different symbol, which depicts the radar screen when performance monitoring is being performed. The label should be changed from "MON" to "PERF MON", or fully written as "PERFORMANCE MONITOR" if possible.
Icon 41 – Gain 		Q47 – Which of the following Icons represents the function to adjust anti-clutter **Rain** control?  **24 (83%)** 2 (7%) 3 (10%) Total 29	Both Icons 42 and 43 performed well in the survey.		
Icon 42 – Anti-clutter Rain Control 		Q52 – Which of the following Icons represents the function to adjust anti-clutter **Sea** control?  2 (5%) 1 (3 %) **34 (92%)** Total 37			
		Q58 – Which of the following Icons represents the function to activate Radar **Performance Monitor**?  **14 (52%)** 4 (15%) 9 (33%) Total 27	The results of question 58 show that Icon 44 did not clearly represent the concept of Radar Performance Monitor.		
Icon 43 – Anti-clutter Sea Control 	Interview	Icon 37 – Standby 	Three interviewees correctly identify the Icon as Standby, the other two interpreted it as Power On/Off. All interviewees recognise the label as an abbreviation of Standby.		
		Icon 38 – Short Pulse	Only one interviewees correctly identify this Icon as Short Pulse. Two others		

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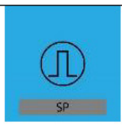
Icon 44 – Performance Monitor 			interpreted the Icon as the Power Button, but subsequently identified the Icon as Short Pulse upon seeing the label. Two interviewees interpreted this Icon as S-band, even after being shown Icon 39 – Long Pulse (without the label "LP"). However, we suspected this misinterpretation to be caused by the interviewees' confusion between the concepts of Pulse Length and Radar Frequency, not the design of the Icons themselves. The argument is, since the symbol in Icon 38 is visually shorter than the symbol in Icon 39, it is more rational to see Icon 38 as X-band and Icon 39 as S-band, as X-band radars use the shorter wavelength. The interviewees, however, answered S-band. Since we made the mistake not following up with additional questions, we cannot be certain of the reasoning behind these two misinterpretations. However, we speculate that the letter "S" in the label "SP" for Icon 38 could have led to these misinterpretations.	be adjusted by either the soft keys on the interface or the hard knobs on the console. The soft keys usually do not employ symbols as icons but rather use the text labels instead. The Icons 40 and 41, as depicted here, are more often used for hard keys on the console. Since the labels were very clear to users, we recommend using the labels Tune and Gain to substitute symbols for Icons 40 and 41 in the case of soft keys on the graphical user interface. On the console, we recommend keeping the concept, but modifying the two Icons 40 and 41 to make them more concrete. **[Icons 42 – Rain and 43 – Sea]** Although both symbols performed well in the survey, the interview sessions showed that Icon 43 was more comprehensible than Icon 42, due to its more concrete design. For this reason, Icon 42 should be modified to better represent the concept of Rain. We can keep the current design of Icon 43. **[Icon 44 – Performance Monitor]**	
		Icon 39 – Long Pulse	All interviewees recognised this Icon as longer pulse setting than short pulse in Icon 38, although they could		

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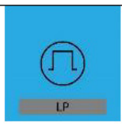
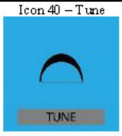
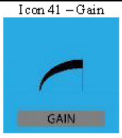
			not decide whether this is Long Pulse or Medium Pulse. One interviewee also commented that if the two Icons for Short Pulse and Long Pulse were not placed next to each other, they would be less comprehensible. These results indicate that all Icons for Pulse Length settings will be usable as long as they are placed next to each other.	Icon 44 performed poorly in both the survey and the interview. This Icon was intended to depict the transmitting and receiving of signals at the radar antenna. However, the symbol was not concrete enough for users to recognise. Additionally, even if users could recognise the Icon as the symbol for transmitting and receiving radar signals, it would still be difficult for seafarers to relate to Radar Performance Monitor. This can happen because seafarers and engineers have different views on Performance Monitor. To an engineer, monitoring radar performance involves transmitting radar signal to the echo box and evaluate the returning performance monitor signal. To a seafarer, performance monitoring involves observing picture of the Performance Monitor patterns on the radar screen. As a result, we recommend changing the current symbol for Icon 44 to another symbol depicting the radar screen when performance monitoring is being performed.	
		Icon 40 – Tune 	Only one interviewee managed to interpret the symbol as Tuning. The rest could not make sense of the symbol but immediately recognise the function upon being shown the label. The interviewees commented that the symbol was too abstract and did not make sense to them.		
		Icon 41 – Gain 	Four interviewees recognised the symbol as Gain control. The fifth interviewee recognised that this was a Radar control, but could not interpreted the symbol. However, upon seeing the label, he was able to recognise this function as Gain. One interviewee commented that the two Icons for Tuning and Gain controls are two		

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			similar and could be confusing. He suggested modifying the Icons to make them more distinguishable. The interviewees also commented that they disliked the symbol, despite being able to recognise it. However, none of them could explain explicitly why they felt that way about the symbol.		
		Icon 42 – Anti-clutter Rain Control 	Three interviewees quickly recognised the icon as Anti-clutter Rain Control. The third interviewee recognised this as a Radar function, but could not recognise it. However, he was able to recognise the icon label. These results show that the symbol is moderately comprehensible. The label, however, is very clear.		
		Icon 43 – Anti-clutter Sea Control 	All interviewees correctly interpreted this Icon as Anti-clutter Sea Control.		
		Icon 44 – Performance Monitor 	None of the interviewees was able to interpret the symbol as Performance Monitor. However, upon seeing the label, all participants were able to recognise the Icon.		

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			The interviewees commented that the symbol for this Icon was too abstract and had no visual clue to Performance Monitor. One interviewer commented that, to him, the symbol imply a ship under rolling motion. A similar opinion was received from the survey participants. The interviewees also commented that the label for this Icon should include the full word or an abbreviation of "Performance". In summary, the symbol for Icon 44 failed to convey the message of Performance Monitor and need to be redesigned.		

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G12 – Chart Functionality

This group contains icons representing chart functionalities.

Original design	Sources	Comments from users	Interpretation of user feedback: Results	Interpretation of user feedback: Discussion	Suggestions
Icon 45  Icon 46  Icon 47 – Manual Update  Icon 48 – Radar Overlay	Survey	Q23 – Which of the following Icons represents the function to adjust **Display Date** to show chart objects active during a specific period?    **19 (50%)** 11 (29%) 8 (21%) Total 38 Q28 – Which of the following Icons represents the function to toggle **LAT/LON Grid** on and off?    **32 (94%)** 1 (3%) 1 (3%) Total 34 Q35 – Which of the following Icons represents the function to perform **Manual Update** for charts?    2 (5%) **31 (84%)** 4 (11%) Total 37 Q40 – Which of the following Icons represents the function to toggle **Radar Overlay** on and off?    9 (26%) 6 (18%) **19 (56%)** Total 34	Results of question 40 and 23 indicate that Icon 46 – LAT/LON Grid could potentially be confused with Icon 48 – Radar Overlay, and Icon 47 – Manual Chart Update could be confused with Icon 45 – Display Date. Users commented that the symbol for Icon 47 – Manual Chart Update should be modified to better represent a buoy and a pencil. Results of questions 23 and 40 indicate that Icons 45 – Display Date and 48 – Radar Overlay were not easily comprehensible and could easily be confused with other icons in this group. Users also commented that the term for Icon 45 should be changed from "Display Date" to "Temporary Objects".	**[Icon 45 – Display Date]** Since the concept of Date-dependent Objects is very abstract, it was to our expectation that users would need to learn this Icon before being able to recognise it. The results of the survey and the interview sessions reflected our expectation. Still, comments from the interviewees show that the symbol for Icon 45 was poorly designed and did not properly depict the intended objects (a calendar and a buoy). As a result, it would benefit users if Icon 45 were designed to be more concrete. Although a survey respondent suggested changing the label from "Display Date" to "Temporary Object", we do not believe the term "Temporary Object" accurately describe the function. The basis of this function is to display the chart as it should be during a specified time, to which the term Display Date is more accurate.	• Modify Icon 45 to make the buoy symbol more realistic. • Change the label for Icon 46 from "GRID" to "LAT/LON GIRD". • Modify Icon 47 to better depict the concepts of Chart Objects and Manual Update. • Modify Icon 48 to better depict the images of Chart and Radar.
	Interview	Icon 45	None of the interviewee was able to interpret the symbol. The label also did not provide		

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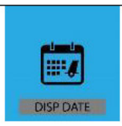
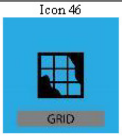
			any assistance to the interpretation. Since the concept of displaying date-dependent chart objects is very abstract, there is no symbol to explicitly depict this function. Therefore, it is expected that users will need to learn of this Icon before being able to use it. Nevertheless, this Icon could be modified to create a better depiction of a calendar and a buoy. The symbol of calendar in this Icon was recognised by only one interviewee, others thought it was a keyboard. Similarly, the symbol of a buoy was recognised by only one interviewee.	**[Icon 46 – LAT/LON Grid]** In the survey question 28, when asking which Icon should representing the function to toggling LAT/LON grid on and off, 94% of the respondent selected Icon 46. However, in the reversed tests during the interview sessions, none of the interviewee could interpret Icon 46 as LAT/LON grid. Still, all interviewees agreed that the design of Icon 46 is logical. These results indicate that Icon 46 follows a logical visual reasoning, but the Icon will not be comprehensible if users are not provided with a "hint" – an accurate point to start the reasoning process. This "hint" can be the location of the Icon on the interface or other Icons in vicinity. In most case, however, the label will be the most usable starting point to for an interpretation process. In this case, all except one interviewees failed to interpret the Icon, even after being shown the label. This result indicates that the label failed its indicating purposes. Therefore, we recommend changing the label from "GRID" to "LAT/LON GRID".	
		Icon 46 	Only one interviewee recognised the symbol as LAT/LON grid. Other interviewees could not interpret the Icon even after being shown the label. However, after being explained the icon's meaning, all interviewees commented that the design is logical.		
		Icon 47 – Manual Update 	All interviewees were able to relate the symbol to the chart and the action of drawing. However, none of them was able to connect these concepts with Manual Chart Update.		

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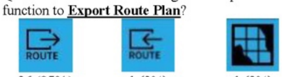
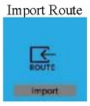
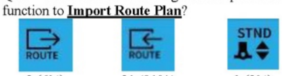
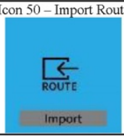
			Upon seeing the label, all interviewees recognised the Icon as Manual Chart Update.	**[Icon 47 – Manual Update]** Although all interviewees could connect the symbol to the concept of Chart and Drawing, none of them could interpret the Icon as Manual Update. In fact, the symbol of a pencil in this Icon caused interviewees to think about the log functions. This result indicates that the symbol for this Icon did not properly communicate the message of Manual Chart Update. For this reason, Icon 47 need to be redesigned to better depict the concepts of Chart Objects and Manual Update.	
		Icon 48 – Radar Overlay 	All interviewees recognised the symbol depict a radar with a chart underneath. All except on interviewees successfully related the symbol to the Radar Overlay function. The interviewee who misinterpreted this Icon answered that he thought the Icon was the function for toggling between ECDIS and Radar mode (for MFD). Since the Icons for different modes of MFD would likely be grouped together on the display, this misinterpretation is unlikely to happen in practice.	**[Icon 48 – Radar Overlay]** There are conflicting results between the survey and the interview sessions. Four out of five interviewees recognise the symbol as Radar Overlay, while only 56% of the survey respondent though Icon 48 to be the Radar Overlay function. These conflicting results occurred due to the following reasons: Since this was the Icon number 48 on the list, the interviewees had been familiar with the general design style of the icon set and could easily recognised the symbol as the depiction of a radar with a chart	

				underneath. This allowed the interviewees to relate to the Radar Overlay function. In the survey, each respondent only answered five questions. As a result, the survey respondents were less familiar with the design style of this icon set and could not recognise Icon 48. These results indicate that the design of Icon 48 is too abstract to be recognised by new users. Therefore, we recommend a new design for Icon 48, which better depicts the concepts of Chart and Radar.	

G13 – Route Plan

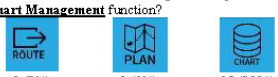
This group contains icons representing functions for managing route plans.

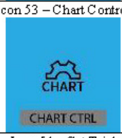
Original design	Sources	Comments from users		Interpretation of user feedback: Results	Interpretation of user feedback: Discussion	Suggestions
Icon 49 – Export Route 	Survey	Q24 – Which of the following Icons represents the function to **Export Route Plan**?  **36 (95%)** 1 (3%) 1 (3%) Total 38		Both Icons 49 and 50 performed well.	Since both Icons 49 and 50 were highly comprehensible, we can keep the current design.	
Icon 50 – Import Route 		Q29 – Which of the following Icons represents the function to **Import Route Plan**?  2 (6%) **31 (91%)** 1 (3%) Total 34				
	Interview	Icon 49 – Export Route 	Icon 50 – Import Route 			

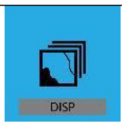
G14 – Groups of Functions

This group contains Icons representing groups of functions and settings.

Sources	Comments from users	Interpretation of user feedback: Results	Interpretation of user feedback: Discussion	Suggestions
Survey	Q25 – Which of the following Icons represents the **Target Settings** group?  **33 (87%)** 3 (8%) 2 (5%) Total 38 Q30 – Which of the following Icons represents the **Radar Configurations** group?  2 (6%) **30 (88%)** 2 (6%) Total 34 Q31 – Which of the following Icons represents the **Chart Settings** group?  2 (5%) 4 (11%) **31 (84%)** Total 37 Q36 – Which of the following Icons represents the **Trial Manoeuver Settings** group?  **30 (88%)** 2 (6%) 2 (6%) Total 34	Results of questions 25, 30, 31, and 36 indicate that Icons 51, 52, 53, and 54 were highly distinguishable from each other.	**[General]** The term "Control" used in Icons 51, 52, and 53 was unclear and confused users. The symbol of a gear used in Icons 51, 52, 53, and 54 implied performance settings. However, only Icon 53 – Radar Control concerned performance settings. Icons 51, 53, and 54 actually represented operational parameters, similar to Icons 55, 56, 57, and 58. This lack of distinction between performance settings and operational parameters confused users, as noticed in the interview sessions. Therefore, we suggest using two different symbols for Performance Settings and Operational Parameters. **[Icon 51 – Target Control]** The label "Target Control" is semantically incorrect. We cannot control any target and, according to the explanation, we do not intend to use this function to control anything. The accurate term for this function should be Collision-avoidance Parameters.	• Designate two symbols for System Performance Settings and Operational Parameters and use them consistently throughout the icon set. • Icon 51: redesign the Icon to indicate Collision-avoidance and Operational Parameters. Also change the label to "COLLISION-AVOIDANCE PARAMETERS" or an equivalent abbreviation. • Icon 52: redesign the Icon to depict the concepts of Radar and Performance Settings. Also change the label to "RADAR SETTINGS" • Icon 53: redesign the Icon to depict the concepts of Chart and Navigation Parameters. Also, change the label to "NAVIGATION SAFETY PARAMETERS", or "NAVIGATION PARAMETERS", or an equivalent abbreviation. • Icon 54: Abolish this Icon and merge with Icon 35 in group G07. • Icon 55: modify the Icon to depict the concepts of Chart Objects and Layers. Also change the label to "CHART LAYERS" more concretely. • Icon 56: Completely redesign this Icon.
	Q41 – Which of the following Icons represents the **Chart Display Settings** group?  **32 (71%)** 3 (7%) 10 (22%) Total 45	Results of question 41 indicate that Icon 55 – Chart Display Setting could be confused with Icon 59 – Chart Management.		

	Q46 – Which of the following Icons represents the **<u>User-selected Chart Objects</u>** group?  **13 (45%)** 6 (21%) 10 (34%) Total 29	Results of questions 46, 51, and 56 show the following: • Icon 56 – User Charts was poorly designed and not comprehensible. • Icon 57 – Route Plan Settings was highly comprehensible. • Icon 58 – Route Monitoring Settings could be confused with Icon 57.	We suggest another symbol to indicate Collision-avoidance and Operational Parameters. The label should also be changed to "Collision-avoidance Parameters" or an abbreviation. **[Icon 52 – Radar Control]** Based on the arguments presented above, we suggest changing the label to "Radar Settings" and using another symbol to depict the concepts of Radar and Performance Settings. **[Icon 53 – Chart Control]** Based on the arguments presented above, we suggest changing the label to "Navigation Safety Parameters", or "Navigation Parameters". We also suggest using another symbol to depict the concepts of Chart and Navigation Parameters. **[Icon 54 – Set Trial]** Since there is already Icon 35 – Trial to execute a Trial Manoeuvre, we recommend merging this Icon with Icon 35 to create a single Icon both for setting up and executing Trial Manoeuvres. **[Icon 55 – Chart Display]** Results of the interview indicate that the symbol did not successfully depict the concept of Chart Layers. Therefore, we suggest modify the symbol design to better depict the concepts of Chart Objects and Layers.	• Icon 57: modify the symbol to depict a plotted Route Plan. • Icon 58: modify the symbol to depict the ECDIS screen when monitoring route. • Icon 59: redesign the Icon to depict both the concepts of Chart and Database.. Also change the label to "CHART DATABASE".
	Q51 – Which of the following Icons represents the **<u>Route Plan Settings</u>** group?  2 (5%) **33 (89%)** 2 (5%) Total 37			
	Q56 – Which of the following Icons represents the **<u>Route Monitoring Settings</u>** group?  **19 (70%)** 8 (30%) 0 (0%) Total 27			
	Q57 – Which of the following Icons represents the **<u>Chart Management</u>** function?  2 (7%) 0 (0%) **25 (93%)** Total 27			
Interview	Icon 51 – Target Control  	This Icon did not make sense to any of the interviewees. Three interviewees could interpret "TGT" as Target, and the Gear as a depiction of Setting or Configuration. Nevertheless, they could not make sense of the Icon. One interviewee could not recognise "TGT" as the abbreviation of Target. Two interviewees commented that the explanation of this Icon in the		

		current S-mode draft was confused between Parameters and Settings. The interviewees considered the term "Settings" to be associated with performance adjustment, while "Parameters" to be associated with controlling system functions. Based on this argument, the interviewees commented that the symbol of a gear imply adjusting performance and thus, not suitable. They also commented that the label "Control" was not suitable for the symbol of a gear and thus, was confusing.	Also, based on the comments of the interviewees, we suggest changing the label from "CHART DISPLAY" to "CHART LAYERS". **[Icon 56 – User Chart]** Results from the survey and the interviews indicated that the symbol for this icon was not comprehensible. The label was also considered confusing. As a result, this Icon need to be redesigned completely. **[Icons 57 – Route Plan and 58 – Route Monitoring]** Icon 57 performed well both on the survey and the interviews. However, based on the suggestion from the interviewees, we recommend removing the word "Plan" from the symbol. Icon 58, on the other hand, was less clear, as seen in the results of survey question 56. Comments from the interviewees suggest the reason to be the abbreviation of "Monitoring" to "MONIT". We recommend using "ROUTE MONITORING" for the label of Icon 58. **[Icon 59 – Chart Management]** Since all interviewees used the term "Database" instead of "Management", we suggest changing the label from "CHART MGMT" to "CHART DATABASE".	
	Icon 52 – Radar Control  	Although all interviewees correctly interpreted this Icon, they commented that their interpretations were based on the previous Icon 51.		
	Icon 53 – Chart Control  	Although all interviewees correctly interpreted this Icon. No further comment was provided.		
	Icon 54 – Set Trial  	All users were able to relate this symbol with Trial Manoeuvre, but none was able to interpret this Icon correctly. Once again, the interviewees commented on their understanding of Settings and Parameter.		
	Icon 55 – Chart Display	None of the interviewees could interpret this Icon. Two		

		interviewees recognised the depiction of layers, but failed to relate to Chart Layer Settings. The interviewees commented that the label was not clear and suggested using "CHART LAYERs" instead.	Additionally, the interviews showed that the symbol did not clearly communicate the message of Chart Management since only one of the interviewees could recognise the Icon. As a result, we suggest modifying the symbol to better represent the concepts of Chart and Database.	
	Icon 56 – User Chart 	All interviewees recognised the Icon as an ECDIS function, all interviewees could interpret the label as an abbreviation of "User Chart", but none of them could understand what "User Chart" mean. One interviewee commented that a similar function is called "Map" on TRANSAS ECIDS.		
	Icon 57 – Route Plan 	All interviewees correctly interpreted this Icon. One interviewee commented that, since the label was "ROUTE PLAN", we could take away the word "PLAN" from the symbol.		
	Icon 58 – Route Monitoring 	All interviewees correctly interpreted this Icon. One interviewee commented that, since the label was "Route Mon", we could take away the word "MONIT" from the symbol.		
	Icon 59 – Chart Management	Only one interviewee recognised the label as managing chart database. Others interpreted the Icon as Chart Layers and Chart Basket (for ordering charts).		

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	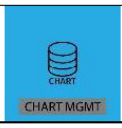	The label was also not clear to the interviewees. After being explained the icon's meaning, all interviewees used the term Chart Database to refer to this function.		

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