WMU Journal of Maritime Affairs
https://doi.org/10.1007/s13437-023-00317-2

ARTICLE

Developing human factors design guidelines for marine electronics — the case of S-mode

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Received: 21 March 2022 / Accepted: 16 May 2023

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 data used in the study include interviews with major stakeholders, official reports of the development work, and personal records of members of the development team. 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

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Published online: 30 May 2023

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, whilst 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

[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*. Geneva: International Organization for Standardisation.

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.

Whilst 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. Whilst most operations are successful, accidents do occur, and improper design of shipboard systems has been identified amongst contributing factors in several accidents (MAIB 2014, 2017; NTSB 2014). Problems arise when the designers/developers focus on technical and economic aspects, whilst 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.

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 that 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 and 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). Amongst 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, whilst there are only limited number of documents on user interface design, both physical and digital (Mallam and 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 amongst 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, abbreviated as “S-mode CG”, 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 and 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 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 whilst, at the same time, have individual goals of defending the interests of the organisation they represented, be it an IMO member state or 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 and 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.

An important question to consider when conducting case studies is the choice between the single-case and multiple-case approach. Meyer (2001) suggests that 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 that a multiple-case approach should be followed if applicable whilst, 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, the 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 and 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 CG, and the first author's personal record. Once this step was completed, the authors commenced the second step, which aimed to validate results of the first phase with perspectives of the major stakeholders. These major stakeholders were those that had the most contribution to the development of S-mode.

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 description 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). Following this approach, this study employs the following three data sources:

1. Official documents including documents submitted to IMO negotiations, reports issued by various IMO organs, and supportive documents from 2007 to 2019. These documents are listed in Appendix 1.
2. Material available to members of the S-mode CG, including email conversations between members and relevant materials published by the group (reports, presentations, and magazine articles) between 2017 and 2019. Contents of these materials were extracted into a compiled text document for subsequent analysis. It should be noted that personal data including email addresses and personal names were excluded to avoid potential ethical issues.
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 CG (2017–2019). In these records, the first author provides his own account of activities performed by members of the S-mode CG, either through his direct involvement in such activities or through information provided to him by other members, as well as his thoughts and interpretations of these activities.

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 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. As previously mentioned, 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 result of this document analysis helped identify key events during the development of S-mode and the actions of each involving stakeholder during each event. Following the completion of the document analysis, the authors proceeded to validate these initial results by consulting other members of the S-mode CG. To this end, the authors conducted interviews with members with the most significant contributions to the development of S-mode.

3.4 Step 2 — interviews with stakeholders

Following the document analysis, the authors identified 30 organisations that contributed to the development of the S-mode guidelines. These 30 organisations, in turn, belong to 17 IMO member states and NGOs, representing different groups of stakeholder in maritime shipping including national maritime administrators, manufacturers, seafarers and maritime pilots, ship owners and operators, research institutions, classification societies, and equipment manufacturers.

Since it was not possible to interview every member of the S-mode CG, the authors had to be selective in identifying the interviewees, focusing on those that have contributed most significantly to the development of S-mode. To this end, the authors conducted a stakeholder analysis using a procedure adapted from the stakeholder matrix version 2 by Kennon et al. (2009). The specific procedure was as follows:

- The authors ranked all 17 IMO member states and NGOs involved in the development of S-mode on two characteristics: technical and political contributions. Technical contribution refers to the contribution of an organisation, through the provision of technical expertise and resources, in drafting the content of the S-mode guidelines. Political contribution refers to the political and diplomatic work that an organisation performed to influence IMO decisions that shaped the scope of S-mode or the status of S-mode as an IMO initiative.

Following this stakeholder analysis, interviews were conducted with members of the S-mode CG ($n=4$) with the most contribution to S-mode. 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 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, whilst 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 emergence 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, 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 major stakeholders. These multiple sources of data allow the authors 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. By sending the interviewees preliminary research findings to prepare before the interview sessions, the authors could have introduced potential biases to the interviewees, which could have potentially affected their subsequent interview answers. Still, these biases were mitigated by triangulation of subjects — having interviewers from four different organisations. 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 the 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 interviewees and two additional members of the S-mode CG. These two additional experts had been involved in the development of S-mode since the emergence of the concept in 2005 but were not interviewed during phase 2 of the 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 CG and interviews of major 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.

3.6 Dual roles of researchers/members of the S-mode CG

An important issue of this study is the fact that the first and second authors were both members of the S-mode CG and were both heavily involved in the development process in the capacity of human factors specialists. These dual roles provide many benefits to address the trustworthiness of this study.

Firstly, their involvement with S-mode allows these two authors to develop a collaborative relationship with other members of the S-mode CG, particularly those who were interviewed during step 2 of the study by the first author. At the same time, this involvement allows the first author to acquire insider knowledge, which created a ground for mutual knowledge between him and the interviewees. In combination, there was a degree of trust established between the first author and the interviewees. Also considering that the first author and the interviewees were affiliated with different unrelated organisations, it can be argued that the interviews were not affected by an unequal power dynamic between the first author and the interviewees. As a result, the continued interaction between the authors and the interviewed members of the S-mode CG, corresponding to the strategy termed "prolonged engagement" by Guba (1981, p. 84), increase the credibility of this study.

On the other hand, however, the dual roles of researcher/practitioners also created potential biases. The first and second authors had their own interpretations of the activities occurred during the development of S-mode. Such interpretations were influenced by their backgrounds as users of navigation equipment and human factors researcher as well as their association with the NI. Consequently, these preconceptions could influence the interpretation of the collected data. Reflexivity is a mean to assess and address the influence of the researcher's subjectivity (Ruby 1980). The first author's personal record, which forms the third data source during step 1 of the study as discussed in Sect. 3.3, was the main tool to aid this refection process. Combining this personal record with the perspectives of the interviewees, the document records, and the view of third author who was not involved in the development of S-mode allowed the authors to compare, evaluate, and identify preconceived assumptions.

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

The findings indicate that during the development of S-mode from the emergence of the concept in early 2000s to the adoption of the S-mode guidelines in 2019, there were five key events that shaped the development process. Figure 1 provides an overview of key events during the timeline of S-mode.

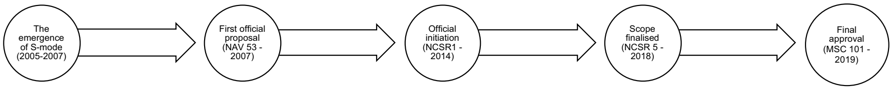

Fig. 1 Overview of the development of the S-mode guidelines

4.1.1 The emergence of the first S-mode concept

There is very limited information in published written records on the emergence of the original S-mode concept before its first official proposal at the IMO in 2007. The main source of information for this period comes from the interviews with members of the S-mode CG, particularly the NI who was the proposal of the original S-mode concept.

The emergence of the original S-mode concept was motivated by the increased level of sophistication and complexity with navigation systems which was observed by the NI in the late 1990s. 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 with the attendance of representatives from several industry stakeholders including equipment manufacturers, seafarers, and academic researchers. Amongst the discussed matters, the delegates were particularly concerned that navigation equipment was getting too diverse in terms of user interfaces and functionalities, and training was focusing mainly on teaching seafarers to use different functions and controls rather than using the equipment to navigate safely and effectively. The delegates proposed a solution was to raise the level of equipment standardisation, which would facilitate training and familiarisation. The NI subsequently submitted a paper to the IMO summarising the issues raised during these conferences. The IMO acknowledged and included these issues and the suggested solution 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 over what had already been standardised at that time 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. This standard interface mode could be manually activated by users. The NI believed that such a stand-alone standard interface would bring improved standardisation whilst manufacturers can still innovate with their brand-specific interfaces.

The idea received supportive feedback from maritime professionals so the NI collaborated with the International Federation of Shipmasters' Associations (IFSMA) during 2005–2007 to propose this S-mode concept to the IMO (Patraiko 2007).

4.1.2 Frist official proposal of S-mode at the IMO

In the 53rd session of the sub-committee on safety of navigation (NAV) in 2007, the NI and IFSMA jointly submitted a paper proposing the S-mode concept as a solution to improve the usability of future navigation equipment (IMO 2007b). This was the first time S-mode was officially introduced to the IMO. Both written reports from IMO organs and the Norwegian delegation as well as inputs from the interviewed members of the S-mode CG provide details of this event.

The original S-mode concept was negatively received by marine electronic companies. Whilst 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.

4.1.3 Becoming a part of e-Navigation

There was limited development on S-mode during the period between 2008 and 2013 as the IMO, during this time, was focusing on developing the e-Navigation Strategy Implementation Plan (SIP). This work 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

[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.

rescue (NCSR) in 2014. Both official IMO records and interviews with members of the S-mode CG, particularly the CIRM, provide details of this event. 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 USA 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 Netherlands, 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).

4.1.4 Defining a scope

Following NCSR1 in 2014, the development of S-mode became an official part of e-Navigation. However, the concept remained abstract, and the priority of the development was to define a specific scope of S-mode. This task was carried out by an informal correspondence group, formed in 2015 under the coordination of Australia.

During 2015 and 2016, members of the S-mode CG conducted research and held workshops and negotiations to determine a scope of S-mode. Records from IMO meetings and interviews with members of the S-mode CG suggest that this was the time when S-mode gradually departed from the original concept of fully standardised interface mode(s) for navigation equipment to 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 CG 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.

A key breakthrough was achieved during the e-Navigation underway Asia-Pacific 2017 conference in South Korea. In this conference, the CIRM proposed an alternative S-mode concept, developed by their internal S-mode technical group.

This alternative S-mode concept, as proposed by CIRM, would not standardise the whole interface but only standardise four features on the displays: icons and terminologies, the grouping of key functions and controls, quickly accessible functions, and default system settings. These four standard 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 CG as this was, by far, the only solution with a clear development pathway. CIRM's proposal was subsequently incorporated into the official scope of S-mode, approved by the NCSR in 2018 (IMO 2018a). The finalised scope of S-mode contained a set of guidelines for consideration of human factors in the design navigation systems and four standard features of navigation displays as proposed by the CIRM. It was expected that S-mode would take the form of an IMO circular, and the development work would be finished by the end of 2019.

4.1.5 Developing contents of the S-mode guidelines and final approval

Following the finalisation of the scope of S-mode in 2018, the main work of the S-mode CG during 2018–2019 was to develop and finalise contents of the S-mode guidelines.

The group followed the working arrangement of an IMO correspondence group where members would work independently and communicate via emails to discuss and make collective decisions. Australia, as the coordinator, collected and distribute information amongst members.

During NCSR 5 in 2018, members of the S-mode CG met at the IMO headquarters and jointly drafted the first edition of the S-mode guidelines, which contained two parts. The first part contained human factors principles for designing navigation systems, drafted based on previous work of human factors specialists amongst 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 CG conducted several studies to evaluate the usability of the standard features as proposed by CIRM and propose alternative designs when necessary. Details of these studies can be seen in IMO (2018b), Vu and Lutzhoft (2018), and Vu and Lutzhoft (2019). The findings were circulated amongst members of the S-mode correspondence group for consideration.

There were four rounds of comments and editing, resulting in four editions of the S-mode guidelines. Decisions were made collectively and with each matter raised, members of the S-mode CG 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 by the Navigation Working Group. The draft was approved with minor changes. More importantly, changes were made to MSC.191(79) and SN.1/Circ.234 to ensure alignment with the new S-mode guidelines. It was decided that the requirements set forth by the S-mode guidelines would have the following implementation dates:

- 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, execution, and conclusion 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 amongst the involving parties. This phase started from the emergence of the S-mode concept and lasted until the adoption of S-mode as an official part of e-Navigation in 2014 (IMO 2014a). The participants involved during this period and their actions are discussed in Sects. 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 Sects. 4.1.3 and 4.1.4.
- Phase 3 — the main objective of this phase was to draft and finalise the contents of the S-mode guidelines. This phase began after NCSR 5 in 2017 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 Sect. 4.1.5.

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 2009, 2010a, b). 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 before the official adoption of S-mode into e-Navigation during NCSR1 in 2014. There was no common goal shared amongst 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 specifically. 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). The authors and the interviewed members of the S-mode CG also observed a similar characteristic 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 amongst e-Navigation solutions. The CIRM, IMPA, Japan, Netherlands, and France did not support S-mode to be a part of e-Navigation whilst the NI, International Chamber of Shipping (ICS), INTERTANKO, Denmark, Norway, Germany, Republic of Korea (ROK), Australia, Marshall Islands, Panama, Kiribati, Nigeria, and Poland supported S-mode. The group that opposed S-mode consisted of IMO members and organisations with strong interests in producing navigation equipment, especially the CIRM.

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 in 2014, 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 both requirements of a basic compact and a level of interdependent amongst the involving parties were satisfied (Klein et al. 2005). 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.

However, the jointed effort to decide the scope for S-mode was hindered by a weak common ground amongst members of the S-mode CG. The group's members came from different backgrounds and had envisioned S-mode differently. There was a strong focus on making S-mode a solution most beneficial to the seafarers who are the end-users of navigation equipment whilst less priority was given to the need of equipment manufacturers who would have to implement S-mode — an issue consistently pointed out by the CIRM. Such a difference 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.

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 CG 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 Sect. 5, 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 worked to develop the contents of the S-mode guidelines. This work, as discussed in Sect. 2, followed the principles of a user-centred design process. However, this development work was undertaken by an IMO correspondence group and also followed the working arrangement 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 additional to mutual knowledge, beliefs, and assumptions, a joint activity is also facilitated by the ability of the involving parties to direct and predict each other's activities (Klein et al. 2005). In this case, there are certain factors in the working arrangement of IMO correspondence groups that lowered the interpredictability and directability amongst members of the S-mode CG.

The first factor to consider is the fact that the S-mode CG, whilst attempting to follow standard steps in a UCD process as recommended in ISO 9241:2010 (ISO 2010), did so in a loosely structured manner. 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 whilst 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. The use of email correspondence meant there were, in many instances, delays in information exchange between members, which affected the decision-making process and led to the group adoption the negotiation strategy of "immediate consensus or nothing" as discussed in Sect. 4.1.5. In other words, 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 topic of maritime human factors and provides additional insights into the consideration of human factors in designing shipboard navigation system as well as the role of the IMO in facilitating such practice through regulatory means.

Documents from regulatory agencies such as the IMO play a critical role in shaping directions in the maritime industry, maritime human factors included. The interviews with members of S-mode CG indicate that there is little incentive for manufacturers to implement something without regulatory requirement. The fact that the standard features introduced in the S-mode guidelines are mandatory significantly increases the impact of the guidelines. However, the case of S-mode also provides insights into the usability of regulatory instruments considering the requirements of the implementors.

As discussed in Sect. 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.

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.

To the author's knowledge, there was no published study investigating this communication gap in the context of marine electronic manufacturing. However, Bader and Nyce (1998) investigate a similar communication gap between social scientists and software developer. They observe that cultural and social knowledge, whilst providing 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-tribe 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, whilst familiar to the scientists, is not easily usable 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 manufacturers when developing relevant regulatory instruments. Specifically, manufacturers require a regulatory instrument to contain specific, testable criteria to demonstrate compliancy.

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, and factors affecting the development process.

The original concept of a fully standardised interface mode, called S-mode, for navigation equipment emerged in 2005 and was first proposed to the IMO in NAV 53 in 2007 as a solution to address the issues of complexity and lack of standardisation in interface design for shipboard navigation equipment. The proposal received both support and oppose from IMO member states and NGOs. In NCSR1 in 2014, the IMO acknowledged the importance of S-mode and officially adopted S-mode as a part of the e-Navigation initiative. In the following years, a correspondence group with delegates from 17 IMO members and NGOs worked to determine the exact scope of S-mode. In 2018, the concept of S-mode was finalised, departing from the original concept of fully standardised interfaces to became a set of design guidelines for interfaces of navigation equipment which also standardises four features on the navigational displays. The content of the S-mode guidelines was subsequently developed following a human-centred approach. The final edition was adopted in MSC 101 in 2019 and will enter into force in 2024.

As an example of IMO's effort to address human factors issues through regulatory means, there were factors affecting the development of S-mode during each phase of process. Firstly, it was the political support from influential member states and organisations that allowed S-mode to become an official IMO project. When determining the scope of S-mode, the progress was hindered by the different perspectives amongst members of the S-mode correspondence group, particularly the primary focus on S-mode to address the needs of end-users whilst neglecting the requirements of implementors — equipment manufacturers. Finally, when developing the contents of the S-mode guidelines, the working arrangement of an IMO correspondence group, where members worked independently and communicated via emails to make collective decision, did not facilitate effective collaboration and lengthened the decision-making process.

Considering the context of S-mode as an IMO initiative, similar future initiatives should align their objectives with the interest of influential maritime nations to secure their support in IMO decisions. The scope of such initiatives should consider the requirements of both end-users and implementors. Also, the planning and execution of such activities should take into account the restrictions associated with procedures and working arrangements at the IMO.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s13437-023-00317-2.

Funding Open access funding provided by Western Norway University Of Applied Sciences This study is funded by the Research Council of Norway and is a part of the first author's doctoral research.

Declarations

Conflict of interest The authors declare no competing interests.

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