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ARTICLE

Investigating the introduction of e-navigation and S-100 into bridge related operations: the impact over seafarers

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Abstract
The present work is focused on analyzing how e-navigation will affect the daily work of seafarers involved in bridge-related operations. Within e-navigation, the International Hydrographic Organization (IHO) is currently working in the development of the new standard (S-100) whose role is to guarantee a homogeneous management of the maritime domain data. S-100 is called to act as the Common Maritime Data Structure (CMDS), it represents the technical framework required to guarantee a wider and better use of maritime data. The mission of the standard is to create a common foundation that can be used for multiple purposes; meteorologists, physicists, and whoever is interested in developing maritime related products will refer to the same standard. Not having a homogeneous type of data processed with standardized procedures will allow a better combination and processing of maritime data. Considering the perspective of Hydrographic Offices, the objective of the present document is to analyze the impact which e-navigation will have over seafarers. The study is focused on the evaluation of the risks connected to S-100-based products and on the analysis of specific bridge operations. Considering that e-navigation products are still at their design phase, being aware of the consequences for the final users is essential to make S-100-based products more customer oriented and to allow seafarers who are involved in bridge operations to get familiar with this new technology.

Keywords E-navigation · S100 · IHO · IMO · ECDIS · Seafarers

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1 Introduction

During the last century, a sensible evolution has characterized navigation; seafarers have passed from the deployment of the sextant and the use of the sun, moon, stars, and planets into the adoption of the Global Positioning System (GPS). GPS has opened the door to the so-called Integrated Bridge system (IBS), the International Maritime Organization (IMO) has defined IBS as *"…a combination of systems which are interconnected in order to allow centralized access to sensor information or command/control from workstations, with the aim of increasing safe and efficient ship's management by suitably qualified personnel"*(Awan and Al Ghamdi 2019). Technical development has affected the work environment for all those seafarers that are part of the bridge team. The work of the Officer of the Watch (OOW), for example, has become not only less time-consuming, but also more accurate. If the route of the ship is considered to be similar to a physical infrastructure (roads, railways), the introduction of new bridge-related technologies have progressively renovated and renewed this facility. Bridge technologies have the task to provide seafarers data and information. In the past, the adoption of new systems onboard have not always introduced new data, most of the time they provided the same data with more accuracy, higher reliability, and usability.

During the last 50 years, the nautical charts nave been characterized by a constant evolution that have led to the electronic navigational charts used today. The transition from paper charts to the Electronic Chart Display and Information System (ECDIS) is the last step that has seen the transformation of an ancient art; in the past navigation has been influenced by the introduction of other technologies like *"the gyrocompass, the sextant and chronometer by radio navigation and binoculars and telescopes by radar"* (Donderi et al. 2004). ECDIS finally has influenced not only the way navigation is performed, but also the workload for seafarers doing navigational watches (Brčić et al. 2019). Despite the evolution of navigation, nautical charts have always a leading role in assisting seafarers and in giving them usable human-readable information. Both paper nautical charts and electronic nautical charts are based on international standards developed and approved by IHO. Maritime standards are an important factor, capable of benefiting both producers and customers, they can help to implement public policy decisions with their economic and engineering impact (Kite-Powell and Gaines 1995). For the future, one of the most important standards under development will be S-100. S-100 is the new IHO's standard. It is not conceived only for hydrographic data as it has the task to guarantee standard procedures for the management of the entire maritime domain data. The standard can be seen as a further step towards the implementation of e-navigation and the digitization of maritime operations. Even though IMO is the primary institution liable for the definition and reinforcement of the general framework for electronic navigation, the contribution of IHO and IALA (International Association of Lighthouse Authorities) is fundamental for the implementation of e-navigation and for its application within the new ECDIS (Martinez de Oses and Juncadella 2019). Within e-navigation, IHO is in charge to develop S-100 as the CMDS; aside from digitalization, the objective of the standard should be also to ensure that information is obtained from reliable sources and that they are exchanged between all the stakeholders in an integrated manner (Arslan and Nas 2022).

Even though the impact of technology and digitalization on the unemployment of seafarers is relatively low (Frey and Osburne 2017) on board vessels, the crew is required to be more and more prepared to handle increasingly automated ships (Sohyun et al. 2020). Being prepared and trained can allow seafarers to have a pro-active approach towards e-navigation and new technologies. Since the advantages of the digital era can be achieved only if prompt actions are taken, understanding how digitalization can affect the maritime operations is essential also for education institutes (Demirel 2020). In relation to the new technologies available, a rethink of the current Maritime Education and Training is necessary (Fonseca and Lagdami 2019). Considering e-navigation as an exogenous environmental factor, knowing in advance how it can influence the work on board can help both producers to be more customer oriented, final users to get ready in time and education institutes to update their training programs. In order to avoid that new technologies create new human weaknesses and change the nature of the current bridge-related errors from human to not human, designers need guidance on how the coordination between the two actors need to be implemented (Lützhöft and Dekker 2002).

The present study is based on a questionnaire that through IHO has been distributed to its Member States. The questionnaire questions have been chosen to understand how the interaction between humans and S-100-based products can be managed. Part of the proposed circumstances are destined to create risk matrices. These questions have been chosen based on similar studies focused on the transition from paper charts to electronic navigational charts (Donderi et al. 2004; Brčić and Srđan 2018; Maro et al. 2020). The rest of the questions are based on the document presented and discussed at the S-100 IHO's working group.

2 The state of the art

Since its adoption by the International Maritime Organization (IMO), the attention over e-navigation, has grown considerably. According to Scopus database, for e-navigation, the most productive year in terms of scientific publication has been 2017; after that peak, the attention stayed high. As far as what has emerged, the literature that analyses the concept of e-navigation, taking into perspective both naval operations and the seafarers involved in bridge related operations has not been sufficiently investigated.

Even though IMO has already considered the human factors and human interface in e-navigation through the adoption of the Standard mode (S-mode) (Bhardway 2013), a specific analysis on both human factor and nautical operations has not been carried out yet. Jeevan et al. have considered human resources as a key factor for the study of the implication of e-navigation on maritime transport. From their work, it emerges that e-navigation has the potential to assist the onboard decision-making process and to allow the reduction of human errors (Jagan et al. 2020). Already more than a decade ago, Baldauf et al. felt the need of further human factor investigation; e-navigation, if properly managed, can provide maneuvring support to seafarers (Baldauf et al. 2011). The e-navigation and S-100 development should always be seafarers oriented; aside from its role for coastal users, it should be capable of assisting seafarers in planning and implementing navigation and in checking their compliance with relevant regulations (Arslan and Nas 2022).

Consequently, to the mandatory requirements for ECDIS of IMO (IMO 1974), the academic interest over the last years have been mainly focused over the study of the introduction of electronic navigational charts and over the introduction of ECDIS. Many studies (Donderi et al. 2004; Brčić and Srđan 2018; Maro et al. 2020) tried to understand how the transition from paper navigational charts affected seafarers. Donderi et al. have shown that the transition from paper charts to electronic navigational charts, the introduction of ECDIS, and its integration with the radar have allowed to lower the work of seafarers. In 2019, after the 2014–2018 implementation period, the level of acceptance of ECDIS by masters and seafarers was analyzed by Brčić and Srđan. Even though many seafarers are in favor of the paper chart withdrawal, others are still convinced that a minimum set of paper charts should be kept as a back-up (Brčić and Srđan 2018). Similarly, for S-100 a variegated acceptance is possible. The attitude on the transition towards electronic charts varies depending on the age of the workers and their rank (Maro et al. 2020). Apart ECDIS and ENCs, for the scope of the present document, it is worth mentioning that other studies have tried to investigate the relationship between seafarers and new technologies (Allen 2009), bridge-related automation problems (Lützhöft and Dekker 2002) and the usage within seafarers of new technologies such as the Automatic Identification System (AIS) (Bailey et al. 2008) or the Vassel Traffic System (VTS) (De Osés et al. 2021). Considering that most of the literature focused on the transition into digital has been published only after the implementation period of ECDIS and other devices, it is reasonable to assume that the S-100 topic will be further investigated in the future after e-navigation operational implementation.

In order to be effective, the S-100 implementation should be accompanied by specific procedures and training, even though there is an increasing dependence on technology, the human element is still central (Patraiko et al. 2020). Among the advantages connected to S-100, specifically for the OOW, Brozovic et al. underlined benefits connected to better decisions taken in situations like the navigation in restricted waters and navigation with particular weather conditions (Brozovic et al. 2021). Within the e-navigation, various information systems are conceived for increasing safety and security at sea (Park D. and Park S. 2014). Seafarers, more in general, have a central role in e-navigation; to maximize the e-navigation benefits and avoid the overreliance on new technologies, they need to be subjected to effective training (Jagan et al. 2020). Automation can improve the safety of navigation only if the navigator is kept updated and is trained to act when the automation fails (Porathe 2016).

In marine accidents, the human factor is considered the main reason of error, 7.6% of human errors are connected to “inadequate tools and equipment” (EMSA 2020). Even though a part of the literature claims that technologies can lead into increasing safety and security, some other authors argue that if not properly managed, the introduction of new technologies on board can be considered a contributory factor to accidents (Tang et al. 2013). In the last years, some marine accidents have been caused by the improper usage or malfunction of ECDIS and the lack of coordination of advanced technologies (Brčić et al. 2019). Beyond the definition given by IMO, it is possible to see e-navigation as an attempt to create a tool capable of minimizing human errors and ensuring the present lack of standardization onboard (Arslan and Nas 2022). From the perspective of regulatory authorities, taking into consideration the human factor during the design phase, can avoid new technologies as being seen as just another hardware component (Karltun et al. 2017). Considering the final user's point of view, usually, the introduction of new technologies within private firms, due to high acquisition costs, is often rushed without planning. It often increases the seafarers fatigue with unnecessary redundant tasks (Suresh et al. 2019). Ismail et al. affirmed that since the digitalization of navigation can be considered a disrupting technology, knowing in advance how it can affect seafarers is also important for educational institutes (Ismail et al. 2014). In safety–critical industries, taking into consideration the human factor for technologies under development is crucial; in this case training can avoid incurring any catastrophic consequences (Allen 2009). Considering that e-navigation is still at its linear growth phase, its operational aftermaths need to be forecasted in advance before its growth starts to be exponential and the disruption point from the current technology is reached (Ismail et al. 2014).

E-navigation can be defined as the paradigm conceived for distributing and sharing maritime data (Park D. and Park S. 2016). The work of seafarers will be affected not only by a different management of maritime data, but also by the distribution method that will be adopted by S-100. Considering that S-100 has been conceived not only for ENCs but also for other type of data like weather or tidal (Park D and Park S. 2015), propaedeutic to its implementation is the establishment of a specific S-100 distribution schema compliant with a variety of not homogeneous type of data. To date, the distribution of ENCs has been managed by the Regional Electronic Navigational Chart Coordination Centre (RENC) (Horst 2000). The maritime community is currently working in developing web cloud technologies like the Maritime Connectivity Platform (MCP) (Weinert et al.2018); MCP represents a communication framework capable of enabling common internet standards into maritime navigation (Jović et al. 2019). The distribution method that will be used for S-100 will affect the work of seafarers and the execution of specific bridge procedures. What will be the distribution schema adopted for S-100 purposes and how it will affect the work of seafarers remains an under investigated topic.

Part of the literature examined is focused on how a better usage of data can affect shipping companies from a business perspective (Yang 2019; Zaman et al. 2017; Adland and Jia 2016; Merrik et al. 2021), its usage for bridge-related activities, however, is still scarce and vague. The most pertinent study pictures e-navigation and human resources in a wider analysis related to transportation efficiency (Jagan et al. 2020). Considering that for shipping companies, the operational risks have higher frequency and a shorter cycle than the strategic and tactical (Son et al. 2019), being capable of dealing more effectively with the execution of navigation with a better usage of maritime data by seafarers can be crucial, not also for the safety of navigation, but also for the operators' cost-effectiveness.

The implementation of e-navigation and S-100 base products will require initial investments that will need to be covered in the medium-long period. Since physical and human capital are complementary, and they are tightly tied together (Fonseca et al. 2018), the conscious management of seafarers within e-navigation will be crucial to guarantee performance and productivity.

The final goal of this work is to create a bridge between the current literature on the transition from paper charts into electronic chart products and the future literature that will focus on the transition into e-navigation services. Being aware of what to expect in the future will be helpful for human resources management, safety of navigation, and the efficiency of bridge-related activities.

3 Methodology

Considering the state of evolution of e-navigation and S-100 products, the questionnaire addressed to the developers (HOs) has been considered to be the optimum choice for the data collection. The questionnaire methodology is useful to profile a specific population (Rowley 2014), and to obtain reliable qualitative data upon which to base the present study. As questionnaires are meant to provide a snapshot of the situation at a specific time (Denscombe 1998), the objective of the present study is to study e-navigation prior to its implementation on board. Similarly, the arguments of other studies focused on the previous transition towards electronic navigational charts and ECDIS have been based on questionnaires (Brčić and Srđan 2018; Maro et al. 2020). In the questionnaire, six Likert scales and multiple choice questions have been proposed to the participants. For a part of the questionnaire whose objective was to build risk matrices, the 5-item Likert scale has been considered the best method for submitting the questions. Through Likert scales, a range of responses can be associated to a principal statement (Croasmun 2011). The usage of the 5-item symmetric scale has allowed to spot also neutrality positions of neutrality; the neutral option has tried not to push the answers towards agreement or disagreement (Joshi 2015). Multiple choices have been used in the case where the analysis could not be structured through the usage of Likert scales.

After its collection, in order to answer the research question and understand what are the strengths and weaknesses of S-100 for seafarers, some data have has been processed through the usage of risk matrices. Risk matrices allow to assign discrete risk categories to the combination of consequence and likelihood of specific phenomena, they can be used to prioritize risks (Duijm 2015). As they provide a graphical method for the assessment of non-quantifiable risks (Jordan et al. 2018), they have been considered a useful tool when answering the research question. In risk matrices, colors (green, yellow, and red) can be used to indicate the level of risk (Cox 2008). Thanks to the data collection and after to the data processing, S-100 strengths and weaknesses for seafarers and bridge operations have been identified (Fig. 1).

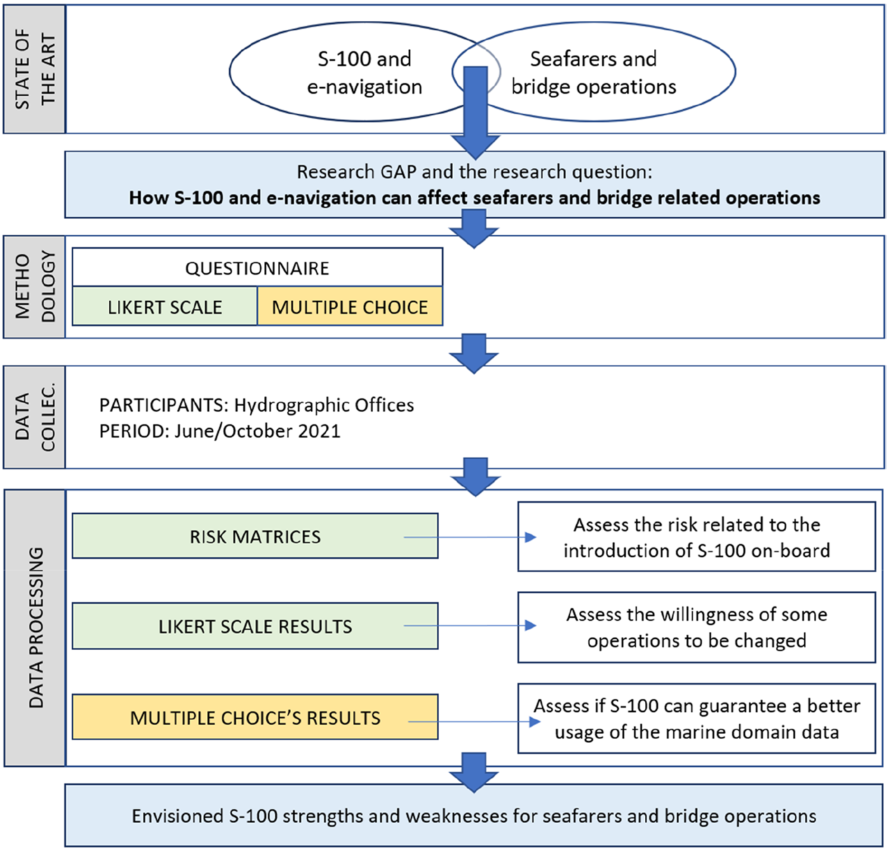

Fig. 1 The research methodology

3.1 The mission, the chosen data, and sample

The mission of this study is to analyze how seafarers will be affected by the introduction of S-100-based products. Being aware of what to expect in the future can be very useful for the various maritime actors; managing in time the introduction of S-100 -based products will be crucial in the e-navigation revolution. Taking the HOs perspective, the research question of the present study is aimed at understanding e-navigation impact over seafarers and specific bridge-related operations.

The data presented and studied have been collected through the distribution of a questionnaire to those Hydrographic Offices members of the IHO. *"IHO is an intergovernmental organization whose members are the governments of coastal States. Established in 1921, the Organization provides a forum for the improvement of services to marine navigation through the discussion and resolution of hydrographic issues at the international level, and assists member governments to deliver these services in the most cost-effective way through their national hydrographic offices*

(IHO 2021)." Through its standards, IHO assures the uniformity of nautical charts, making the work of seafarers easier and safer (Kastrisios and Pilikou 2017). Based on the UNCTAD data related to national's fleets, its members represent 856 million dwt of the 2.1 billion world declared dwt (UNCTAD 2021). The questionnaire has been divided into three sections whose goals were to study how S-100 will affect HOs, seafarers/bridge-related operations and shipping companies; the present work is focused in discussing the outcomes related to seafarers and bridge operations.

IHO and the member HOs have been the main actors involved in the evolution of e-navigation and S-100, for centuries they have been involved in developing nautical products and services for seafarers. Considering their knowledge of e-navigation and their experience with seafarers, HOs can be considered the ideal sample upon which to base the present study. The development of S-100-based products is still at his design phase and is still not operational, the questionnaire has been an obligatory choice for collecting data.

The full implementation of S-100 -based products is forecasted for 2030 (IHO 2021), until that date HOs represent the main actors involved in their evolution and the main sample to be considered to answer the proposed research question. HOs have the availability of highly specialized personnel that have been involved for over a decade in S-100 development. Through the proposed questionnaire, participants have been called to consider and evaluate specific situations. All participants have been asked to rank and quantify their opinion into multiple choice and Likert scale answers. Even though the data collected is bound to the circumstances proposed, having a restricted and specific set of situations analyzed have allowed the present study to process homogeneously data into common and standardized information.

3.2 Approval, distribution, and participation to the questionnaire

The distribution and the promotion of the present study's questionnaire has been possible thanks to the cooperation with the International Hydrographic Organization and its Inter-Regional Coordination Committee (IRCC). The research proposal first has been submitted to IRCC, and then it was presented and approved by its members during the 2021 annual meeting (IRCC13). The questionnaire was divided into three sections, to the section analyzed in this document, one participant did not given any answers, all the other MS filled out the entire questionnaire and their data has been used for the present analysis. Responses from 43 IHO's member states (MS)[1] have been used for the present study.

All responses have been collected directly by IHO. Answers were collected from June 2021 until October 2021. Based on UNCTAD 2021 data, the responding states represent 653 million tons of the 856 million tons represented in IHO (76,1%) (see

[1] The 43 participants have represented the following countries: Argentina, Australia, Bangladesh, Brazil, Canada, Chile, China, Colombia, Croatia, Cyprus, Cuba, Denmark, Ecuador, Estonia, Finland, Germany, Greece, India, Indonesia, Islamic Republic of Iran, Italy, Japan, Latvia, Lebanon, Malaysia, the Netherlands, New Zealand, Norway, Pakistan, Peru, Poland, Portugal, Republic of Korea, Romania, Singapore, Slovenia, South Africa, Spain, Suriname, Sweden, Turkey, the UK and Northern Ireland, the USA.

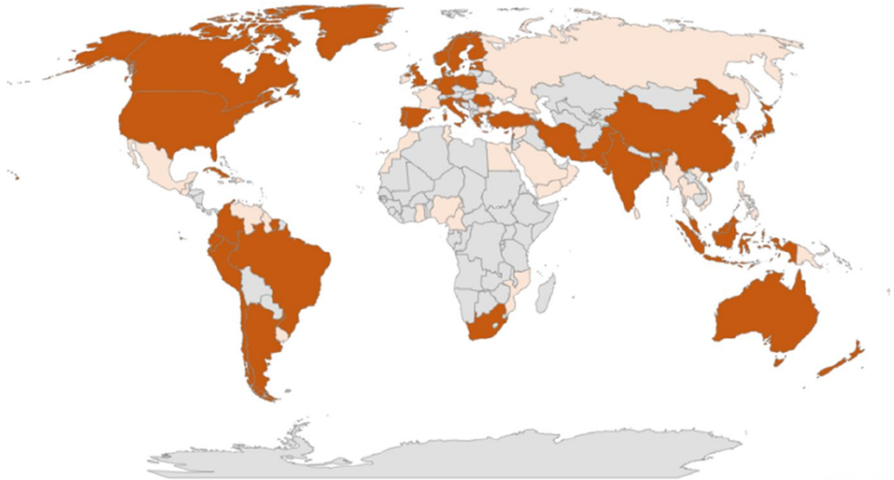

Fig. 2 In dark orange Member States that have taken part in the study, in light orange the other IHO's MS

Fig. 2). Except for the African continent, participants are homogeneously spread throughout the world; of relevance is the representation level of both North and South America. One participant to the questionnaire did not give answers to the questions related to the part analyzed in this study.

3.3 Data processing

As shown in Fig. 1, the data collected has been processed into three groups.

Part of the data collected has been used to create a risk matrix destined at analyzing how S-100 can affect some activities and procedures. In the matrix, the likelihood and impact of specific situations was analyzed, and the data was merged. To each answer and to the average answers, colors associated to different risk level have been assigned. Matrices have allowed to elaborate data into quantified and comparable results. The comparison of the results is then used to prioritize risks and to direct the attention over possible opportunities. Considering both the emerging character of e-navigation and the uncertainty that gravitates around the operational usage of S-100-based products, the results are expected to be balanced and the "medium" options to be the most rated ones.

Through the usage of Likert scales, the second set of questions have been used to analyze if specific bridge-related activities are destined to be affected by the implementation of e-navigation on board. For this type of analysis, two levels of details have been provided: the first one is more generic and is meant to investigate the likelihood of some activities to change, the second is more specific and tries to relate specific S-100-based products with specific activities and duties.

The other questions have been used to detect the overall sentiment over the usage and distribution of maritime data. The multiple choice answers have been used to establish the general sentiment over this topic. Distribution of nautical data can

Table 1 The likelihood matrix

	Considering the application of S-100 products on board, what are the negative consequences for the bridge personnel (choose one option per column) - LIKELIHOOD?							
	Seafares can over trust S-100 and be less aware. (A)		Displaying data on a screen may cause over-scaling problems like what happens with ENCs. (B)		Older personnel may find difficult to get familiar with the system. (C)		More attention on electronic navigation will reduce the performance of traditional navigation. In case of distress, personnel would not be able to react. (D)	
LIKELIHOOD	%	#	%	#	%	#	%	#
Almost Certain	4.7	2	9.3	4	27.9	12	9.3	4
Likely	23.3	10	23.3	10	30.2	13	27.9	12
Possible	53.5	23	51.2	22	34.9	15	51.2	22
Unlikely	9.3	4	11.6	5	2.3	1	7.0	3
Rare	7.0	3	2.3	1	0.0	0	2.3	1
NO ANSWER	2.3	1	2.3	1	4.7	2	2.3	1

affect the work of seafarers and their approach in managing ocean-related information, new cloud-based distribution processes have the potential to improve how data will be used on board.

4 The results

4.1 The S-100 implementation's risk matrix

Considering e-navigation and the future S-100 ECDIS as an endogenous factor capable of affecting the work of seafarer, it is important to be aware of the possible risks connected to its implementation. A risk evaluation at the design phase can support the new ECDIS development both from the hardware and operational point of view.

The matrix shown in Table 1 focuses on specific risks, the results reported are related to the likelihood of a specific downside. Participants were asked to rate each risk, choosing a value that goes from "Almost Certain" to "Rare." All the circumstances proposed obtained similar results, "Possible" was always the most chosen option. The usability of S-100 products by older personnel is the factor that looks more problematic to respondents, more than 57% of respondents chose "Almost certain" and "Likely" options.

The reluctance of senior navigational ranks and commanding officers to new technologies have already emerged in the past in the transition from paper chart (Maro et al. 2020) to date. Many seafarers think that a full reliance on electronic charts should be avoided (Brčić and Srđan 2018). Considering that seafarers like the Master or the Chief Mate represents part of the older age personnel embarked, risk C, if not properly managed, they can make the implementation of e-navigation onboard less effective. The new ECDIS should be an evolution of the current

Table 2 The impact matrix

	Considering the application of S100 products on board, what are the negative consequences for the bridge personnel (choose one option per column) – IMPACT?							
	Seafares can over trust S100 and be less aware. (A)		Displaying data on a screen may cause over-scaling problems like what happens with ENCs. (B)		Older personnel may find difficult to get familiar with the system. (C)		More attention on electronic navigation will reduce the performance of traditional navigation. In case of distress, personnel would not be able to react. (D)	
IMPACT	%	#	%	#	%	#	%	#
Insignificant	2.3	1	0.0	0	4.7	2	2.3	1
Minor	18.6	8	30.2	13	18.6	8	30.2	13
Moderate	34.9	15	39.5	17	51.2	22	20.9	9
Major	25.6	11	27.9	12	20.9	9	32.6	14
Catastrophic	16.3	7	0.0	0	2.3	1	11.6	5
NO ANSWER	2.3	1	2.3	1	2.3	1	2.3	1

one, it should be capable of introducing innovation while preserving a familiar environment. The undergoing efforts with the dual fuel ECDIS capable of displaying both current and future charts on the same device, seems useful to give time to senior personnel to get familiar with the new technology.

After evaluating the likelihood, participants were asked to assess the impact of the same risks considered before (see Table 2). Considering the median value, for three of the four proposed circumstances, the impact is considered "Moderate," in one case the median value was "Major."

The loss of knowledge of traditional navigation is the consequence that may have the highest impact over the bridge personnel; the transition towards e-navigation should not be an excuse to forget how traditional navigation is performed. Being capable of sailing without electronic support is still crucial for the safety of navigation and in being able to respond to vessel distress. The concerns emerged in the "impact" table should be taken into consideration when rethinking the seafarers' training programs, the need of familiarization with e-navigation should not sacrifice the knowledge of traditional navigation tools.

Table 3 is aimed at processing together the likelihood and impact results into a risk matrix. To better evaluate the proposed risks, it is convenient to assign a value from 1 to 5 to each impact and likelihood option given, the product between the value is useful to better assign a risk level to each of the circumstances proposed. (low risk value 1, high risk value 25) Options A, B, and C, all with a value of 9 [3(moderate) × 3(possible) = 9] are ranked as medium risk. Option D, with a value of 12 [4(major) × 3(possible) = 12] has a medium–high risk. None of the results converged into the green part of the matrix; the introduction of S-100 products on board needs to be handled with care, as the chance of negative consequences is not negligible. Additionally, it is important to underline the fact that no risks converged in the red part of the matrix. The loss of knowledge of traditional navigation would result in being the riskiest circumstance to take place.

Table 3 The risk matrix based on the majority of answers

	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Almost certain 5					
Likely 4					
Possible 3			B-C-A 9	D 12	
Unlikely 2					
Rare 1					

Table 4 Comparison between different risks

	Red cells	Yellow/Or-ange cells	Green
A	19.0%	59.5%	21.5%
B	16.6%	52.4%	31.0%
C	35.7%	50.0%	14.3%
D	26.2%	42.8%	31.0%

Table 5 Risk matrix for "Seafarers can over trust S100 and be less aware"

	Insignificant 1		Minor 2		Moderate 3		Major 4		Catastrophic 5	
	#	%	#	%	#	%	#	%	#	%
Almost certain 5	0	0.0	0	0.0		0.0	1	2.4	1	2.4
Likely 4	0	0.0	4	9.5	3	7.1	2	4.8	1	2.4
Possible 3	0	0.0	3	7.1	11	26.2	6	14.3	3	7.1
Unlikely 2	1	2.4	1	2.4	1	2.4	0	0.0	1	2.4
Rare 1	0	0.0	0	0.0	1	2.4	1	2.4	1	2.4

Starting from the same data, it is interesting to analyse them, not referring to the majority of answers and the median values per option but referring to the position given in the matrix to each participant.

In Table 4, it is possible to compare the various risks analyzed in the previous matrices (Tables 5, 6, 7 and 8) and their position in the matrix. In contrast to what has emerged from the previous analysis, the alternative whose answers have been processed into more red-type cells is "Senior personnel that may find it difficult to get familiar with the system" (risk C). On the contrary, the option with the weakest "red" representation is option B (displaying data on a screen may cause

Table 6 Risk matrix for "Displaying data on a screen may cause over-scaling problems, like what happens with ENCs"

	Insignificant 1		Minor 2		Moderate 3		Major 4		Catastrophic 5	
	#	%	#	%	#	%	#	%	#	%
Almost certain 5	0	0	0	0.0	0	0.0	4	9.5	0	0
Likely 4	0	0	2	4.8	6	14.3	3	7.1	0	0
Possible 3	0	0	7	16.7	9	21.4	4	9.5	0	0
Unlikely 2	0	0	4	9.5	2	4.8	1	2.4	0	0
Rare 1	0	0	0	0.0	0	0.0	0	0.0	0	0

Table 7 Risk matrix for "Older personnel may find difficult to get familiar with the system"

	Insignificant 1		Minor 2		Moderate 3		Major 4		Catastrophic 5	
	#	%	#	%	#	%	#	%	#	%
Almost certain 5	0	0.0	2	4.8	7	16.7	2	4.8	1	2.4
Likely 4	1	2.4	2	4.8	6	14.3	5	11.9	0	0.0
Possible 3	0	0.0	5	11.9	9	21.4	2	4.8	0	0.0
Unlikely 2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Rare 1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

Table 8 Risk matrix for "More attention on electronic navigation will reduce the performance of traditional navigation. In case of distress, personnel would not be able to react"

	Insignificant 1		Minor 2		Moderate 3		Major 4		Catastrophic 5	
	#	%	#	%	#	%	#	%	#	%
Almost certain 5	0	0.0	0	0.0	1	2.4	1	2.4	2	4.8
Likely 4	1	2.4	3	7.1	2	4.8	4	9.5	2	4.8
Possible 3	0	0.0	8	19.0	4	9.5	9	21.4	1	2.4
Unlikely 2	0	0.0	2	4.8	1	2.4	0	0.0	0	0.0
Rare 1	0	0.0	1	2.4	0	0.0	0	0.0	0	0.0

over-scaling problems like what happens with ENCs). As already mentioned (Maro et al. 2020), the concerns related to senior personnel have past roots. The usability of a new system and products should consider that the target audience will vary in age and rank.

Table 9 Evaluating the changes in bridge-related activities

The introduction of S-100 may require your organization to adapt to a new production factor and to a different way of managing your institutional activity. For each cost component, choose how much it will be affected by the introduction of S-100 (choose one option per column):										
	The usage of the Radar and other TLC equipment (A)		The usage of those data that today are contained in Nautical Publications (B)		The execution of navigation in restricted waters (C)		The Officer of the watch's job (D)		The Lookout activity (E)	
	%	#	%	#	%	#	%	#	%	#
Almost certain	14.0	6	30.2	13	30.2	13	20.9	9	9.3	4
Likely	23.3	10	39.5	17	34.9	15	34.9	15	18.6	8
Possible	23.3	10	16.3	7	20.9	9	23.3	10	25.6	11
Unlikely	25.6	11	4.7	2	4.7	2	11.6	5	23.3	10
Rare	4.7	2	2.3	1	2.3	1	0.0	0	14.0	6
I prefer not to answer	7.0	3	4.7	2	4.7	2	7.0	3	7.0	3
No answer	2.3	1	2.3	1	2.3	1	2.3	1	2.3	1

4.2 Changes in the bridge-related activities

The introduction of S-100 on board will require seafarers to refer to the new ECDIS where the various S-100-based products can be used. S-100 will allow delivering on just one device information that currently is provided on different formats and on different devices.

The circumstances analyzed in Table 9 is meant to analyze the impact of S-100 on basic bridge activities (questions A and B), more advanced bridge operations (C) and the work of specific seafarers (D and E), they have been chosen based on the previous swift to ENCs (Donderi et al. 2004; Brčić and Srđan 2018; Maro et al. 2020) and on the current Standard of Training, Certification and Watchkeeping for Seafarers (STCW).

The answers processed have not given homogeneous results over the various situations analyzed. The integration of the radar and other TLC equipment together with ECDIS has been one of the main innovations introduced in the last decades with electronic charts. From the results, HOs considers this process ascertained and unlikely to be affected by S-100-based products. The analysis of the other circumstances have underlined that the impact of S-100 over bridge activities is evident; e-navigation is expected to change the way some work and duties are carried out. It is possible to affirm that e-navigation is destined to affect various bridge-related activities, further studies are necessary in order to understand how. In order to get the best from S-100-based products, the bridge team should be aware of how their work can change in the upcoming years.

After having analyzed in general some main activities carried out by the bridge's team, respondees have been asked if they have any idea on how the availability of S-100-based products will affect seafarer's routine and tasks. To the

Table 10 How S-100 will affect navigation's tasks

For each of the following activities, based on the relevance for the seafarer, assign a value from 1 to 5: 1 Very Low, the current procedure won't be affected; 2- Low, minor impact on today's procedures; 3 – Medium, Large impact that can be managed with current procedures; 4- High, High impact that will need to rethink current procedures; 5 –Very High, extreme consequences, current procedures cannot be used anymore; 9– I prefer not to answer							
	1	2	3	4	5	MEAN	MEDIAN
	Very low	Low	Medium	High	Very high		
	%	%	%	%	%		
Combination of data for weather route (S-412)	0.0	20.8	29.2	37.5	12.5	3.4	4.0
Better utilization of currents and wind data in order to reduce fuel consumptions (S-111 and S-412)	0.0	16.7	29.2	33.3	20.8	3.6	4.0
Better awareness of navigational warnings and increase in safety of navigation (S-124)	12.0	16.0	24.0	32.0	16.0	3.2	4.0
Water level Information for Surface Navigation(S-104) can overstep the limits of the low spring water level sounding data and the usage of Tides Chart.	4.2	12.5	20.8	45.8	16.7	3.6	4.0
S-102 (Bathymetric surface) and S-127 when talking about mega vessel operations.	0.0	8.7	17.4	52.2	21.7	3.9	10.0

question "S100 will give availability of not homogeneous data structured into layers into a single device. Do you have any idea on how this can affect the seafarer's daily work?" Of participants, 55.8% chose option "Yes." For the ones that have answered "Yes," the question reported in Table 10 was proposed. The circumstances proposed have been chosen based on the peculiarities of some specific S-100-based product specification and on specific activities whose automatization has to date not been institutionalized at IMO level. In activities like the evaluation of the weather conditions, the influence of currents over the drift, the tidal computing and the precise knowledge of the sea floor for specific operations, e-navigation has the potential to revolutionize the current procedures.

All the circumstances proposed obtained similar results that vary from "Medium" to "High." The various S-100 product considered have the potential to have a high impact over the performance of specific operations; the current procedures and practices need to be revised in order to get the best from the new technologies. Table 10 underlines that, apart from the changes listed in Table 9, nautical and maritime operations can be affected by e-navigation. Understanding in advance what are those circumstances that are more exposed to S-100 revolution will be useful to forecast operational opportunities and threats connected to its implementation onboard. Practical applications can be useful to attract private firms to S-100 and to promote the widest implementation of e-navigation on board.

Table 11 Usage of data for seafarers

How probable is that S100 guarantee a more conscious usage of maritime data for seafarers?		
	%	#
Almost certain	25.6	11
Likely	51.2	22
Possible	20.9	9
Unlikely	0.0	0
Rare	0.0	0
No answer	2.3	1

4.3 S-100 and the usage of data on board

E-navigation, through S-100 will allow the digitalization of the maritime domain data and its usage within a common standard. It would be of interest to investigate if this process has the potential to lead into a more conscious usage of maritime data for seafarers. One of the most appealing challenges for S-100 is the possibility to change the way data and information is used and processed on board. In Table 11, participants were asked to express their opinion about the possible changes that S-100 can introduce in the usage of data.

The majority of participants member states (51.2%) consider S-100-based product likely to be capable of guaranteeing a more conscious usage of the maritime data. The results showed a general confidence that maritime data can benefit from e-navigation and S-100. S-100 guarantees standard procedures in managing maritime domain data and allows non-homogeneous type of data to be compatible and to be processed together into useful information. The enhancement of various maritime data on one device (the new ECDIS) will allow seafarers to have better access to nautical information. A more conscious usage of maritime data and information can lead into improved safety of navigation.

4.4 S-100 base-product distribution process

The distribution of e-navigation products will require some changes in the distribution method used today. The type of data that will need to get on board is not homogeneous and the various products have diverse updating needs, especially when considering the frequency. Depending on the method that will be chosen for S-100 distribution, the work of seafarers can be subject to changes.

As already mentioned in "Sect. 2," the maritime community will need to decide what distribution method is more appropriate for S-100 data. Seafarers work and bridge operations can be affected by the distribution of nautical data and information. Web services have the potential to guarantee a continuous flow of data and information and to automize the updating activities. Participants were asked to choose which distribution method is more appropriate to be applied to e-navigation products.

As shown in Table 12, HOs agree that a change in the distribution is possible in the future; web cloud technologies may change the distribution method used today.

Table 12 Which distribution method is more appropriate for S-100-based products

Which of the following methods is forecastable for S10X Products distribution:		
	%	#
The current S-57 structure will be fine also for S-10X type products.	9.3	4
A combination of the current procedures and web cloud technologies will be used. The cloud technologies will be used only for those products that are updated very often.	20.9	9
A combination of the current procedures and the web cloud technologies will be used. The S-57 distribution schema will be still available for those area with internet connectivity problems.	48.8	21
S-10X type products will be distributed through a cloud technology.	7.0	3
I prefer not to answer.	11.6	5
No answer	2.3	1

From the results, it is possible to affirm that participants are not convinced in overtaking the current distribution method and in relying only on web technologies. The full reliance on web cloud seems to be unlikely to be adopted.

5 Influencing S-100 ECDIS implementation policy

In the next years, for institutions and for private companies, the results presented in the previous section can be useful when taking S-100 ECDIS-related decisions. Considering that when developing new technologies, the needs of the final users should be considered starting from the design phase (Noy et al. 2015), IMO and the other institutions involved in S-100 ECDIS development should be fully aware of the necessities of seafarers. Even though ECDIS is a standard produced by the regulatory authorities rather than a market mechanism (Kite-Powell 1995), its adaptation to the needs of seafarers is fundamental for enhancing its usability and its contribution to the safety of navigation. Shipping companies should also be aware of the new technologies threats and opportunities and adequate training should be guaranteed (Allen 2009); the results of the present study can be useful to address their future training programs. Finally, education institutions can use the results of the present study when understanding how to cope with e-navigation, with emerging technologies and when defining the new competencies that seafarers need to develop in order to handle the ship efficiently and safely (Demirel 2020). In 2019, Brčić et al. in a study related to the current ECDIS have linked the level of acceptance of ECDIS with educational processes (Brčić et al. 2019). A faster shift to educational processes can guarantee a more effective implementation of e-navigation onboard.

From the “S-100 implementation’s risk matrices,” it is possible to affirm that the results obtained are in line with the criticality already emerged in the transition from paper charts to ENCs (Sohyun et al. 2020; Maro 2020) and with the previous studies focused on the overreliance on the current ECDIS (Weintrit 2008). In the next years, the outcome of the present study should be kept in consideration when writing the Product Specification of the new S-100 ECDIS. In order to make ECDIS implementation on board more efficient, special attention should be given to the human–machine interface and to the system reliability. For seafarers already familiar with ECDIS, its usage should be designed to be straightforward. When referring to reliability and Safety of Navigation, the S-100 ECDIS should overtake the current ECDIS limits. Taking into consideration the criticalities emerged in the transition from paper charts to electronic charts can be a starting point for avoiding the same mistakes in the future with e-navigation. From the analysis, concerns connected to the possible loss of knowledge of traditional navigation also emerged, this result should be considered when rethinking the new training programs for seafarers. In future, on one hand there is the need to introduce seafarers to e-navigation and to S-100-based products, on the other hand, there is the need to preserve the knowledge of traditional navigation and traditional nautical practices (e.g., plotting the course, fixing the position, nautical astronomy).

From the second part of the study, what emerged was that through a better usage of maritime data changes in the bridge duties are likely to happen. The work of seafarers and the practice of nautical operations is destined to be affected by the introduction of S-100. A specific training focused on S-100-based products can be useful to help seafarers to be ready to get the best from e-navigation. The new ECDIS should be designed to further emphasize its role of decision support system; considering in time its possible usage for the weather route or mega vessel operations is crucial for its effectiveness.

6 Conclusions

For investigating how S-100-based products will affect seafarers and bridge related activities, the participation of 43 over 95 IHO's member states (representing 76,1% of the total declared tonnage at IHO) can be a good statistical sample over which conclusions can be drawn for this study.

The first part of the study was conceived for building risk matrices where the data collected was processed and enhanced in two types of analysis, one based on the average results and the second one on specific answers. From both the analysis presented, participants agree that the usage of S-100-based products may introduce some risks on board. All the risks presented have obtained significant shares of answers in the red and orange part of the matrix, this means that a certain degree of risk distributed throughout the various participants is perceived. By the first analysis proposed (a matrix build using the median values chosen), the circumstance that looks more sensible is risk D. More attention on electronic navigation will reduce the performance of traditional navigation. In case of distress, personnel would not be able to react. From the second analysis proposed (a matrix where the individual answers have been considered), risk C (senior personnel may find it difficult to get familiar with the system) emerged to be the most challenging circumstance, which needs to be managed.

The second part of the study has been designed in order to understand how some bridge-related activities are likely to change due to e-navigation implementation. Apart from "The usage of the Radar and other TLC equipment" (activity A), all the circumstances proposed have obtained results between "Likely" and "Possible," activity A is considered the least likely to change. Interesting are the results obtained in matching S-100-based products with practical consequences, the most rated option for all the circumstances has been “High.” Respondents think that the introduction of S-100 will have a high impact over the current activities proposed and a rethink of the current procedures will be required. By all the answers processed in the second part of the study, it is possible to underline the expectations of member states, that S-100-based products in all probability will affect some bridge operations and practices and the current procedures and practices will need to be updated.

The final part of the study is focused on data usage and distribution. Respondents are confident that S-100-based products are likely to guarantee a more conscious usage of the maritime data. When it comes to dealing with data distribution, even though cloud technologies look appealing, a total detachment from the current distribution method looks unlikely for respondents. The option with most answers is “A combination of the current procedures and the web cloud technologies will be used. The S-57 distribution method will be still available for those areas with internet connectivity problems.” The answers show that even though HOs are interested in considering new cloud-based-emerging technologies, they are not yet capable of completely going beyond the present distribution method.

6.1 Lesson learned and impact

By all the answers collected and processed, S-100-based products are conceived as an innovation with both positive and negative aspects. The main advantages are connected with a more conscious usage of maritime data and the related improvement in efficiency on board. The negative aspects are connected to the risks that the e-navigation can introduce on board. The successful outcome of the introduction of e-navigation will depend on how the advantages and risks are faced and managed.

The purpose of this study was to increase the awareness on S-100 implementation on board and to underline, in time, opportunities and threats that can affect seafarers. Forecasting the possible S-100-related consequences can help shipping companies in dealing with external positive and negative factors. A higher awareness over seafarers can help HOs and IHO in being more costumer oriented and in designing more effective S-100 product specifications.

6.2 Limitation and future research

The present study has been focused on analyzing a specific perspective that belongs to Hydrographic Offices, it would be interesting to investigate the same problem considering both the private producers of navigational systems and the perspective of seafarers. The two analyses can be useful to understand how e-navigation is perceived at different levels and to compare the seafarers, the producer of navigational systems and the HOs expectations.

To better evaluate the results obtained by the present study, in the future, after S-100 implementation on board, a similar study and questionnaire can be distributed once again to HOs. A comparative analysis between the results obtained prior and after could be useful in understanding how the perspective of HOs has changed over time.

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Declarations

Conflict of interest The authors declare no competing interests.

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