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From Paper to Digital: The Impact and Hidden Challenges of Mandatory ECDIS on Maritime Safety and Seafarer Practice

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ABSTRACT: This paper explores the impact of the Electronic Chart Display and Information System (ECDIS) on the safety of navigation and seafarers' professional practices. As ECDIS has become the primary tool for navigation, its proper use is critical for ensuring safe maritime operations. Drawing on data from a questionnaire completed by 154 active seafarers, this research investigates how ECDIS influences situational awareness, the use and management of safety settings, training adequacy, and system-related challenges. The findings reveal that while most respondents recognise ECDIS as a tool that enhances navigational safety, significant concerns remain regarding human error, insufficient training, and inconsistent application of safety settings such as the safety contour. Additionally, steering errors during restricted water manoeuvres and system crashes emerged as recurrent safety concerns. The study highlights the need for improved standardisation, targeted training, and more effective integration of human and technological elements to ensure optimal ECDIS use. The results offer actionable insights for enhancing ECDIS implementation and maritime safety standards.

1 INTRODUCTION

Maritime navigation is a complex process encompassing voyage planning, execution, and continuous monitoring of a ship's movement along a predetermined route. During navigation, an officer of the navigational watch (OOW) has approved navigation equipment at their disposal with a greater or lesser degree of integration. One of the most important Navigational Information Systems (NIS) is the Electronic Chart Display and Information System (ECDIS). According to [1], introducing ECDIS has reduced navigation risks by giving OOWs more time to focus on their tasks, improving visual display and situational awareness, and enabling more efficient navigational chart updating. However, the effectiveness of the ECDIS and its usage, and consequently the safety of navigation, largely depend on the abilities of the individual OOW. In other words, how the OOW operates the system is crucial for successfully performing navigational tasks and achieving conditions for safe navigation.

ECDIS is no longer a novelty in maritime navigation but acts as the primary navigation tool. However, it should be emphasised that inappropriate use of the system by OOWs or specific technical deficiencies can threaten navigation and maritime safety and, consequently, negatively impact the marine environment, cause material damage, and endanger human lives.

According to [2], which analysed maritime accidents related to the use of ECDIS, it is noticeable that most of them did not occur due to technical problems but due to human errors. The most common and significant errors include failure to use alarms effectively, failure to use the automatic navigation route check function, inadequate chart scale,

inadequate adjustment of safety parameters, and insufficient knowledge and training of the OOW. The analysis of accidents in which the ECDIS played a role as one of the contributing factors has confirmed this [3-7].

Furthermore, according to the guidelines of the International Maritime Organization (IMO) [8], OOWs' over-reliance on NIS can lead to human error and, consequently, a threat to the ship's safe navigation. Therefore, during ECDIS training and education, it is necessary to include all potential known and observed problems that may arise when operating the system. The IMO assumes that using the ECDIS system contributes to safer navigation. However, previous research [2,9-12] indicates several factors that indicate the opposite, which is one of the elements of motivation for this research.

Inadequate use of navigation equipment can result in a maritime accident or an unwanted event such as a near-miss. In [11], 80 reports of maritime accidents from 2008 to 2018 were analysed to determine whether the ECDIS system was a significant contributing factor to accidents. The authors determined that in 22 maritime accidents, the ECDIS or electronic navigation charts (ENC) had a significant impact on the occurrence of the accident. The results of the analysis identified insufficient knowledge of OOWs, shortcomings in navigation procedures, and inadequate ECDIS safety settings, with a special emphasis on alarm settings, as significant factors contributing to accidents. Furthermore, in [13], the authors analysed 25 grounding accidents related to inadequate use of the ECDIS. According to the results, in 22 out of 25 groundings, the situational awareness of navigation officers reached only the first level (perception) and did not develop further. One of the causes of groundings was inadequate situational awareness associated with ECDIS alarms. According to the authors, automation helps process the collected data to facilitate decision-making. Still, at the same time, it often excludes the OOW from the decision-making process during navigation. In this state, the OOW develops inadequate situational awareness because he is unaware of the automation's performance and the features it is supposed to control. Being outside the decision-making process is not a big problem when automation works well. Still, when it fails, the OOW cannot identify the problem in time, potentially leading to an accident.

Furthermore, the problem of inadequate situational awareness is most often reflected in how navigation officers do not adequately use all the safety functions of the ECDIS [13]. In addition, the seriousness of human error consequences that occur during pilotage and other navigation operations, such as navigation in restricted areas, has been confirmed [14]. According to [14], understanding and identifying the procedures during such operations is extremely important to arranging navigation devices and equipment on the navigating bridge effectively and conducting adequate training of the OOWs. The study results showed that during pilotage and navigation in restricted areas, the possibility of human errors has increased, the most common cause of which is a lack of situational awareness. The authors suggest further research to quantify the cause-and-effect relationships between errors due to failure to take adequate actions and lack of situational awareness.

This study seeks to examine the challenges of ECDIS implementation based on the experiences and perceptions of active seafarers. The primary aim of this paper is to analyse the impact of ECDIS on maritime navigation safety as perceived by the seafarers and their professional practices.

2 LITERATURE REVIEW

Previous research indicates various problems and difficulties recognised when using the ECDIS. The paper [15] addresses the technological advancements in shipping, pointing out two major issues: inadequate education and training for seafarers, and the human element that can contribute to accidents when operating modern navigation systems. The authors reference an accident where a ship ran aground because the navigational watch officer failed to identify a hazard (shallows) on the ENC, attributed to the night mode of the display. The authors noted that switching to a different display mode (day/dusk/night) could have highlighted the hazard. The paper emphasises the need for user-friendly automated systems and calls for a standardised design, configuration, and installation approach. Furthermore, the authors recommend that equipment manufacturers engage closely with OOWs while developing navigational devices to prevent issues related to poor design, installation, and usage of automated systems.

The previously identified issues with displaying navigation charts on system displays and prior surveys and research findings related to navigation information systems are discussed in [16-19]. The authors highlight various potential issues at different levels, including those associated with system installation, maintenance, operation, and navigation. They also address knowledge of the system, Electronic Navigational Charts (ENC) production, and the traditional versus simplified representation of symbols on ENCs. As noted in [12], effective use of the ECDIS necessitates appropriate knowledge and experience. New technologies may give OOWs a misleading sense of safety due to the vast amount of data and options available, while others may feel overwhelmed and struggle to adapt. Errors can arise from discrepancies between systems produced by different manufacturers, leading to system acceptance challenges due to usability variations. The authors recommend a revised strategy for ECDIS training and operation education, asserting that a mere five-day training period is inadequate for mastering all the functionalities of ECDIS, particularly for OOWs with significant navigational experience using PNC.

In addition to the issues above, [20-22] highlight concerns regarding ECDIS training and education, suggesting possible solutions. While there is no strong evidence that experienced seafarers will better accept the system [23], the necessity to tailor ECDIS education to specific navigational tasks [24] has been acknowledged. It is crucial for the OOW to remain cognizant of the system's limitations and to conduct appropriate checks [9,25,26]. Even with maritime authorities striving to enhance the competence of

seafarers, human error continues to be one of the primary contributors to maritime accidents, significantly influenced by insufficient situational awareness [27]. According to [28], poor passage planning stemming from incorrect assessment of safety navigational factors hampers the ability to identify navigational hazards. These elements, along with a lack of operational understanding, excessive reliance on the system, and potential errors within the positioning system, increase the risk of maritime incidents. Thus, it is vital to implement effective passage planning practices and simulator training that incorporates potential equipment failures for safer navigation.

The previous research has highlighted several gaps. Although earlier studies have looked at the effect of ECDIS on navigation, there has been little extensive collection and analysis of seafarers' direct insights about its benefits, drawbacks, and related challenges. Most existing research primarily focuses on accident reports and case studies, with insufficient quantitative data from a varied group of seafarers encompassing different ranks and vessel types. Although there is a recognised need for improved ECDIS training, minimal research has directly asked seafarers about their views on the effectiveness of current training. While previous work has noted issues with colour contrast and symbol clarity, survey-based research is scarce detailing how seafarers encounter these problems in real situations. This questionnaire-based study aims to produce a larger, statistically significant dataset to improve understanding of ECDIS usage in practice. It identifies gaps in training programs by examining questionnaire responses related to training sufficiency and competency levels. By systematically analysing survey data from active seafarers, this study enhances existing research and provides actionable insights for improving the effectiveness and safety of ECDIS implementation in maritime navigation.

The main objective of this study is to assess how ECDIS influences maritime navigation safety and professional seafaring practices. This study intends to fill existing gaps by documenting the real-world experiences of active maritime professionals and offering empirical insights that can improve ECDIS implementation and training standards.

3 METHODOLOGY

The questionnaire was developed using insights from previous studies, the authors' professional experiences, and informal interviews with active OOWs. It was intended for shipping stakeholders, specifically a targeted and experienced group familiar with ECDIS's advantages and possible disadvantages. OOWs, masters, and other stakeholders, including equipment manufacturers and navigation safety inspectors, completed the questionnaire. During the questionnaire's preparation, a pilot survey was created and distributed to experienced officers, who provided feedback and opinions. The questionnaire was validated and somewhat modified based on the respondents' expertise. The survey was available online from December 7, 2021 to December 6, 2022, with a virtual snowball sampling method used to distribute the questionnaire.

The questions can be categorised into three basic types: open-ended, closed-ended, and combined. The survey questionnaire has several interconnected components, including six sections and 51 questions. However, to achieve the aim of this study, responses to 22 questions were analysed, and findings were discussed.

Given the limited accessibility of seafarers, the questionnaire was distributed using a Virtual Snowball Sampling method, which is effective for reaching dispersed or hard-to-access populations [29,30]. Moreover, various maritime agencies were reached out to for distributing the questionnaire, and LinkedIn was also utilised as a social platform. To eliminate bias, the questionnaire was designed to be anonymous and confidential. For respondents unable to complete the survey online, the questionnaire was printed on paper and delivered to the ships. The questionnaire was completed by 203 respondents, 154 of whom were active seafarers. Therefore, only those responses were taken into account for this study.

4 RESULTS AND DISCUSSION

Figure 1 presents the respondents' ranks and sea service time. Most respondents (61%) are masters, staff captains, chiefs, and first officers. 64% of respondents have ten or more years of sea service, making them experienced seafarers.

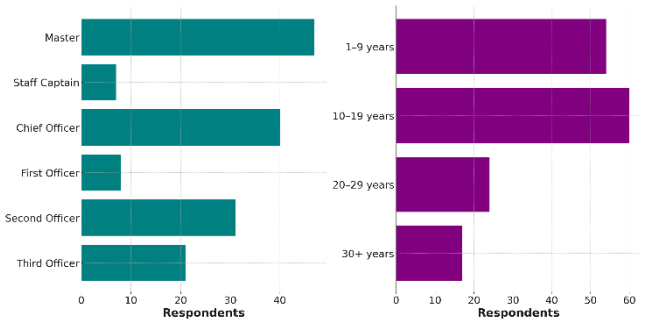

Figure 1. Respondents' ranks and sea service time.

Moreover, 82% of respondents are experienced in working with ECDIS and PNC. Of these, 16% used only ECDIS for passage planning and navigation, while only 2% used only PNC.

4.1 *Situational Awareness*

Because situational awareness was recognised as one of the most important factors for navigation safety and contributing to maritime accidents involving inadequate ECDIS usage, several questions were intended to examine whether respondents experienced situational awareness-related problems during navigation, especially while hand steering in restricted waters. Table 1 presents questions dealing with situational awareness during manoeuvring in restricted waters.

Table 1. Respondents' experiences with steering errors in restricted waters.

Question	Yes (%)	No (%)
When manoeuvring in restricted waters and in closed-loop communication, have you ever witnessed the wrong order given to the helmsman?	79	21
When manoeuvring in restricted waters, in closed-loop communication, have you ever witnessed the wrong execution of the given order by the helmsman?	85	15

According to responses, most seafarers experienced a wrong order given or executed by the helmsman. In addition, when asked to specify the likelihood of a potential threat to navigation safety, 66% of respondents stated that the potential threat was likely. This finding indicates a significant problem, because steering errors (wrongly given or executed orders) might cause serious accidents such as groundings or collisions. If they occurred in narrow passages, the effects of such accidents could be more significant. Therefore, the respondents were asked whether they agreed with the following statement: „Safety of navigation would benefit from a system that raises the alarm in case of wrong helm orders or their execution." More than half of the respondents (56%) agreed with it; 27% remained neutral, while 17% did not agree. In addition, the respondents were asked whether modern navigation has decreased situational awareness and caused us to over-rely on electronic aids for navigation. Interesting answers were received here: 38% of respondents agree, 31% are neutral, while 31% do not agree with the statement.

4.2 *Usage of ECDIS safety settings*

ECDIS safety settings intend to improve navigation safety, reduce accidents, especially groundings, and enable safety awareness during passage planning and navigation. However, ECDIS settings must be adjusted appropriately and changed to affect safety positively. Because OOWs enter ECDIS safety settings, companies should give instructions or guidelines on how to do it adequately. Such procedures significantly improve maritime safety and facilitate the passage planning process. Therefore, the respondents were asked whether their company defined safety contour (the most important safety setting) and their opinion on the possibilities of changing values during the voyage. Furthermore, as large waves could affect Under Keel Clearance (UKC) and, in extreme cases, even cause groundings, respondents were asked whether they consider wave height while passage planning in restricted waters. The questions and responses are presented in Table 2.

The safety contour is one of the most important parameters in the ECDIS settings. According to previous research, many companies have prescribed instructions for calculating the UKC value and setting the safety contour. Based on the responses, 93% of respondents stated that their companies have prescribed procedures for setting the safety contour. Given the importance of this parameter and the fact that all OOWs have access to change the settings, there is a potential risk of incorrect or inappropriate setting of the safety contour value. Therefore, when asked whether everyone should be allowed to change settings, 70% of respondents stated that only certain members of the navigational watch should be allowed to change these settings. In comparison, 30% of respondents thought the opposite, which is the case in practice. Moreover, most respondents consider wave height when calculating UKC, while less than half (33%) experienced wave impact on charted depth (reduced). As most respondents stated that their company set up procedures for safety contour settings, they were asked: „Please specify which data you utilise to define the Safety contour setting?". Figure 2 presents how respondents determined the safety contour.

Table 2. Respondents' experiences and opinions on ECDIS safety settings.

Question	Yes (%)	No (%)
Did your company set up procedures for the "Safety contour" definition?	93	7
The "Safety contour" parameter is a crucial safety setting, but its wrong setup can lead to serious accidents. Do you think changing the "Safety contour" settings should be limited (password protected or prescribed by Shipboard Directive) only to certain Bridge team members?	70	30
During the passage planning and monitoring process in restricted waters, do you consider the expected wave height and its possible impact on the charted depth?	69	31
Have you ever experienced the wave impact on the charted depth?	33	67

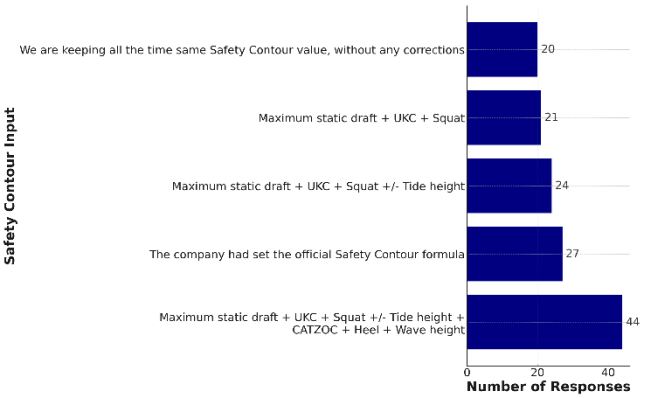

Figure 2. Safety Contour setting calculation on board respondents' ships.

Based on Figure 2, it is evident that there is no standardised way to determine this value, and that different methods and data are used, not all of which are necessarily safe for navigation. In [31], the authors elaborated on the limitations of the ECDIS display, data reliability, the importance of alarm management, and adequate safety settings applicable to Very Large Crude Carrier (VLCC) tankers. ECDIS must demonstrate data reliability and availability that are equivalent to official paper navigation charts (PNCs). Adequate situational awareness is significantly enhanced by recognising and accurately interpreting all objects on the system display. The paper emphasises the crucial necessity of appropriately configuring ECDIS safety settings and the need for OOWs and Masters to understand and use adequate safety depth and safety contour values.

4.3 *ECDIS Training and System Design*

Previous studies and accident case reports recognised the importance of adequate ECDIS training and OOWs'

competence. Respondents were asked to state their opinions and agreements in Table 3.

Table 3. Respondents' opinions on ECDIS training.

Question	Median	Standard Deviation
In your current role, do you think you possess sufficient knowledge about the ECDIS system to use it proficiently and flawlessly?	5.0	0.77
Regarding further system development, do you think you could benefit from additional ECDIS-related training and enhance your knowledge about system utilisation?	5.0	1.19
Do you agree that ECDIS-related training should be tailored according to the trainee or officer rank on board and adopted according to the current involvement with the system?	3.0	1.22
Do you agree that continuous professional development, in terms of further educational training, is needed for all navigational ranks to keep up with the latest advancements in navigation information systems and related emerging technologies?	4.0	0.84

(1) Strongly Disagree, (2) Disagree, (3) Neutral, (4) Agree, (5) Strongly Agree

The median values on the first two questions in Table 3 show that respondents believe they are adequately trained and well-competent for ECDIS usage and could benefit from additional training. However, opinions remain mostly neutral when considering tailoring ECDIS training according to rank. Moreover, respondents agree that continuous development is needed to stay up to date with emerging navigational systems and technologies. Similar findings were discovered in [32], where the authors explored ECDIS education and training globally, particularly emphasising the training system utilised in the Republic of Croatia. They found that ECDIS Generic Training certification achieved a 100% success rate, while ECDIS Type Specific Training reached 90%. Although the duration of generic training is uniform across all maritime education centres, the eligibility criteria for candidates vary among participants. Given the differing regulations across various countries, it is essential to recognise that many respondents desire more in-depth training to familiarise themselves with the system, highlighting that the current training duration is inadequate. The authors concluded a clear need for ongoing similar analyses, engaging all relevant stakeholders, including legislators and seafarers until an optimal solution is identified [32].

Furthermore, the seafarers were asked to state the most frequent issues and problems detected when using ECDIS. Figure 3 presents problems encountered by the respondents.

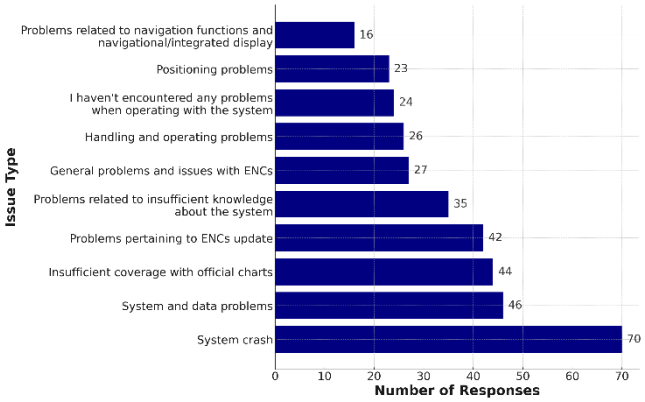

Figure 3. The most frequent ECDIS usage problems recognised by the respondents.

As shown in Figure 3, system crashes are the most frequent issues detected by the respondents, followed by system and data problems and insufficient coverage with official charts. These issues must be addressed to improve navigation safety and facilitate OOWs' ECDIS usage. Moreover, ECDIS-related training could include recommendations for solving some of the issues presented in Figure 3, which could improve OOWs' competence and knowledge of the system.

As previous studies recognised design, standardisation, and usability, it was considered relevant to examine seafarers' opinions on ECDIS standardisation and their experience with chart symbol misinterpretation (Table 4).

Table 4. ECDIS design, standardisation and usability

Question	Median	Standard Deviation
Would better standardisation of the ECDIS interface and settings improve safety and usability?	4.0	0.71
Have you experienced issues related to misinterpretation of ENC symbols due to colour mismatch, scale (zoom in/out), display mode (Day/Dusk/Night), or illumination?	2.0	0.86

(1) Strongly Disagree, (2) Disagree, (3) Neutral, (4) Agree, (5) Strongly Agree

The study [33] examined maritime incidents where the ECDIS played a direct or indirect role, particularly in cases where ships were detained by Port State Control (PSC) Inspections due to issues with the ECDIS or the OOWs' inadequate training in its operation. The findings indicated a lack of standardisation in terminology, system settings, screen displays, and functions among various ECDIS manufacturers, significantly impacting navigational safety [33]. As shown by the responses, respondents believe that maritime safety and usability of systems would be improved, which is in line with findings presented in [33]. Furthermore, although according to the median value, respondents did not experience issues related to misinterpretation of ENC symbols, related accidents confirm that adequate display mode usage is significant for safe ECDIS navigation.

In the end, the respondents were asked whether they agreed with the statement that implementing the ECDIS has contributed to navigation safety. Most respondents (84%) agreed with this statement, 13% remained neutral, and only 3% disagreed. The responses highlighted the importance of ECDIS implementation and showed that seafarers have

positive opinions and consider it an important tool enabling safer and easier voyage planning and navigation.

The OOW must be competent and know how to use a range of techniques for positioning the ship and generally conducting navigation, including, but not limited to, individual navigation methods. A certain presence of situational awareness is inevitable for safe navigation procedures. However, most respondents believe that modern navigation information systems, despite the advantages they have brought, reduce situational awareness and contribute to an overreliance on technological achievements. As examined in [34], overreliance is a significant problem that leads to a loss of situational awareness. Therefore, crosschecking positions by other means, such as radar or other navigational methods, is of utmost significance for safe navigation. Furthermore, ECDIS education and training must be enhanced, and all possible system drawbacks must be included, along with recommendations for reducing human error. Hence, ECDIS education and training should be adapted to reflect the most frequent problems seafarers encounter and address them adequately. Besides training for seafarers, as noted in [35], ECDIS training for Port State Control (PSC) officers should also encompass ECDIS issues that seafarers encounter and facilitate the identification of substandard ECDIS usage onboard ships.

5 CONCLUSIONS

In general, but especially in paperless navigation, misinterpretation of ENC symbols, inadequate alarm use, and human error during helm orders in restricted waters emerged as recurring concerns. These findings reinforce prior research suggesting that while ECDIS can enhance navigational precision, it can also contribute to a decline in active watchkeeping and awareness if not used with critical oversight. Collectively, these thematic insights emphasise the multifaceted nature of safe ECDIS operation. They highlight the interplay between human skill, system clarity, and organisational investment in training and standardisation. The findings validate the need for holistic approaches that address technological and human elements in designing and deploying maritime navigation systems.

System crashes, problems with the system and data, including chart updates, insufficient coverage of official charts, and insufficient knowledge, continue to appear as important, perceived problems despite the fact that the ECDIS transitional implementation period has passed.

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