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Overreliance on ECDIS Technology: A Challenge for Safe Navigation

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ABSTRACT: The Electronic Chart Display and Information System (ECDIS) became the central navigational tool on modern ships. The system comprises numerous navigational and other components, each of them with its limitations and reliability. Due to ECDIS's revolutionary features, navigators are tempted to place excessive reliance on the system. Such reliance on it as a sole navigational aid is undoubtedly a problematic issue. The proposed paper is a segment of a systematically carried out research among ECDIS stakeholders. ECDIS EHO (Experience, Handling, and Opinion) research aims through research activities based on a user-centred approach to develop and improve the educational framework.
The overreliance on the ECDIS system motivated the proposed research, which focused on system users' opinions and practice regarding confirmation of the accuracy of information displayed on ECDIS, particularly concerning positional sensors. Analysis of answers collected by the ECDIS EHO questionnaire represents a backbone of the research supported by previous achievements. The answers have been categorized and discussed, revealing certain worrying aspects referring to the system's positional error experienced by users. Furthermore, preferred methods of cross-checking ECDIS information have been identified and have differed among respondents based on their rank on board. Additionally, answers indicate certain doubts between users' interpretation of the best confirmation method and the actual selection of the used method. The importance of cross-checking navigational data in avoiding overreliance and maintaining situational awareness has been presented in the conclusion chapter and the proposal for further work.

1 INTRODUCTION

Modern-day navigation has been strongly influenced by the technology revolution, particularly by implementing ECDIS in 2018. Navigational bridges are becoming abundant with automated systems with a humane machine interface. In such an environment, a navigator's attention is easily moving from the bridge window and real surroundings to the electronic presentation of information obtained by numerous sensors. Such deprivation of attention may lead to a lack of situational awareness. Situational awareness is defined as being aware of situation and hazards around you and their effect on you, now and in the future [12, 17]. Apart from losing focus on the environment, overreliance on the automated system may erode basic navigation skills, including orientation and spatial knowledge, which is useful when automation eventually fails [43]. Unfortunately, in recent years large numbers of accidents were caused by an overreliance on technology and the lack of chronic unease. Accidents included overreliance on ECDIS, Global Navigation Satellite System (GNSS) and Automatic Radar Plotting Aid (ARPA), and failure to use traditional navigation skills [56]. Obviously, overreliance on technology is problematic even when all equipment is working correctly. As equipment errors are inevitable, overreliance becomes even more problematic. Cross-checking of information obtained by single navigational aid by visual, radar, or any other available means is characteristic of a prudent navigator. Among all other navigational aids, the possibility for overreliance on ECDIS is probably the greatest. This is due to its power of integrating, which differs it from any other navigational system before. It is a navigational system consisting of hardware and software incorporating a great part of navigational equipment. In the ECDIS context, this equipment is considered as sensors, not as standalone devices.

This paper presents research conducted within the project ECDIS EHO (Experience, Handling and Opinion). The crucial part of the research is an international questionnaire conducted among the officers of the navigational watch. It considers their experience and the capacity in which they are engaged. This paper analyses the part of the questionnaire that focuses on navigators' opinions and practices regarding confirmation of the accuracy of information displayed on ECDIS. This paper aims to identify potential problems in using the ECDIS system, focusing particularly on ECDIS overreliance. The background chapter refers to the ECDIS general aspects, concentrating on overreliance on ECDIS as a complex system integrating a variety of navigational aids. The survey methodology has been demonstrated with the ECDIS EHO survey's general characteristics and this paper's research interest. Results bring up analyze of answers of a targeted group on questions of interest of this research paper.

2 BACKGROUND

Integration of various navigational data received by the navigational officer through visual observation and from navigational instruments represents a crucial part of safe navigation. Until recently, navigators were integrating all received data personally to complete the picture of the surrounding. Filtered and integrated data were further used by the navigator in the decision-making process. To assist navigator, ECDIS integrates numerous navigational instruments, becoming a focal system in safe and efficient navigation [4, 9]. In fact, its real value is defined by the synergy it provides [49]. According to IMO performance standards, ECDIS should be connected to positioning, heading, and speed source [21, 26]. These sensors are called mandatory sensors as they are required for the system's full operability. Additional sensors include a great range of navigational devices. Presently the most common devices used to fulfil official requirements are satellite navigation receiver (SNR) (ship's position fixing system, GNSS receiver), a gyrocompass, and a speed and distance measuring device (Figure 1).

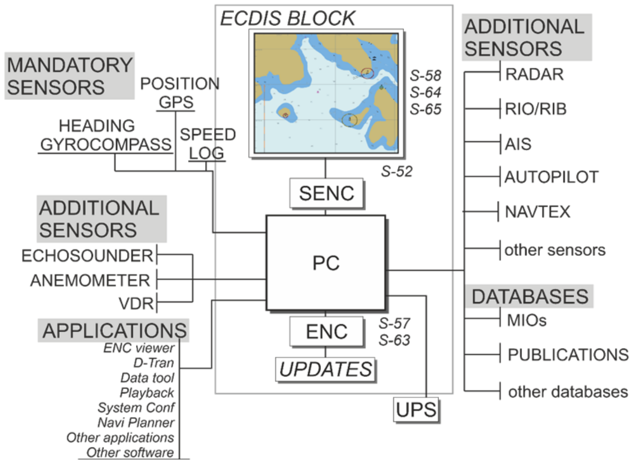

Figure 1. ECDIS layout [9]

Despite apparent benefits by integrating numerous navigational instruments, there is a risk to supplant traditional navigational routines, especially visual observations. The false impression of technology infallibility connected with poor situational awareness and erosion of basic navigational skills have the potential to cause an error and lead to ECDIS assisted accidents. Officer of Watch (OOW) oriented to ECDIS display, relying entirely on technology, and neglecting visual observation through the bridge window is undoubtedly a serious problem [7, 42, 58]. Cross-checking information by other navigational means is the primary countermeasure for overreliance. It serves to detect anomalies, and it is considered a routine navigational procedure. To constantly scrutinize information obtained by various sources, OOW has a limited capability, especially in confined waters. The substantial problem is that the meaning of reliance is very abstract, and its value cannot be measured. It is hardly possible for any OOW to judge an adequate level of reliance, and if OOW is expected not to trust technology, it will create an abnormal professional and psychological atmosphere [51]. OOW has no choice but to rely on information provided by ECDIS, always considering equipment limitations. Information provided by the ECDIS system consists of information obtained by sensors and cartography information provided by an electronic navigational chart (ENC). Both categories have their limitations, which could negatively affect officer reliance on the ECDIS system.

Additionally, the system is vulnerable to cyber-attacks, a relatively new factor affecting safety of navigation. The increasing risk of cyber-attacks is recognised by shipping industry; however industry is not fully prepared in facing emerging challenges [3]. ECDIS and its typical back arrangement presents perfect environment for cyber security threats connected with malicious codes distribution [53].

Recognizing these limitations, it is possible to address certain shortcomings and solve them through the educational process. The risk of overreliance on ECDIS and the necessity for training to avoid using ECDIS as the sole reliable aid of navigation was recognized by the Maritime Safety Committee [19]. Not only training but rather a wide range of activities should be used to solve this issue. It is a matter of long-term activities to create proper navigational culture starting firstly from the educational process, subsequently by meticulous onboard procedures, supervision of OOW by the master, and finally training.

3 OVERRELIANCE

3.1 *Overreliance on sensors*

Good seamanship requires some healthy scepticism about each piece of equipment, however sophisticated and precise it could be. Such scepticism is part of what is known as chronic unease [15]. ECDIS system is a complex system integrating a variety of navigational sensors, each with its advantages and disadvantages. Knowing the limitations of sensors and controlling them is a prerequisite for safe usage of the ECDIS system. System output can only be as accurate as the information entered into it or expressed as "garbage in – garbage out."

3.1.1 *GNSS*

ECDIS's fundamental advantage is that the ship's position is continuously and automatically plotted on ENC. Such a position is obtained mostly by GNSS, a space-based system that has significantly changed navigation history. The system first used onboard as a standalone apparatus that provides accurate position to be plotted on the paper navigational chart (PNC) has become a hidden system feeding ECDIS with position data. The best-known GNSS system is Global Positioning System (GPS), but others are Russian GLONASS or European Galileo. In normal operation, GNSS/GPS will give a position accuracy of around 5-10 m. In order to achieve improved accuracy within 1 m, a Differential GPS (DGPS) is used. DGPS is a generic name for augmentation systems based on ground stations, satellites, or can take the form of a data service enabling fast acquisition of information [53].

Overreliance on GNSS's position could be tracked even to 1995, and the grounding of Panama flagged passenger ship Royal Majesty [41]. This incident is well known as an incentive to adopt the performance standard for the integrated bridge system. The incident root cause was the wrong position indication, caused by a detached Global Positioning System (GPS) antenna cable. Instead of GPS position, the automated display showed a Dead Reckoning Position (DP). As a result, Officers of Watch (OOWs) were not aware of the actual position, which was 17 NM away from the assumed position. All navigating officers were heavily reliant on GPS position and did not use any method to cross-check position. Available methods included position fixing by LORAN C, presence of coast in vicinity detectable by radar, and finally visual observations of fairway buoys. This accident was caused by technical failure, but besides system-related vulnerabilities of GPS, there is also propagation and interference weakness. When passing through an atmospheric medium, the signal is vulnerable to disruptions, while large errors could result from multipath.

Furthermore, GPS signals, due to their weakness, are vulnerable to unintentional and intentional interference, resulting in possible denial of service over large geographical areas [16, 55]. Intentional disruption includes jamming, spoofing, and meaconing [28, 55]. Accordingly, numerous maritime threats connected with GPS interference have been reported in recent years over the regions affected by political tensions [34, 35].

Since 1995 and the grounding of Royal Majesty, GNSS has become even more important as a navigation tool. Due to its great precision, reliability, and simplicity, there is a considerable risk of overreliance on GNSS [29]. Furthermore, it is tempting for navigational officers to pass charted hazards much closer than advisable [37, 40, 62]. ECDIS is heavily dependable on GNSS, used as the primary position source on most of today's merchant navy. Usage of secondary positioning source in ECDIS system as redundancy is a matter of safety of navigation. Regrettably, despite some possible global positioning candidates, the secondary position source is mainly the second GNSS receiver [8]. Two receivers of the same global positioning systems are not an ideal safeguard of position accuracy. Other than secondary positioning source, the appropriate countermeasure for overreliance on GNSS is using a traditional line of position (LOP) and manual plotting on ECDIS. This method serves as a verification of the ECDIS position source. Position checking interval is normally prescribed by the company ship management system (SMS), where OOW has to cross-check information obtained on ECDIS by other methods. These methods include radar and visual observations. The problem is that under normal conditions, the position obtained by these methods is far less accurate than GNSS, so we are using an inferior method to cross-check the superior source of position. [50]. The answer to that could be cross-checking by several methods, rather than one, in order to cross-check information obtained by ECDIS. Relying only on GPS position as a sole navigation technique without conjunction with other methods is, putting it bluntly, bad seamanship. Such a growing tendency endanger crew, ship, and her cargo [37].

3.1.2 *Speed and measuring device*

Accuracy of measurement of speed and distance measuring device is prescribed by the International Maritime Organization as 2% of the speed of the ship, or 0.2 knots, whichever is greater [22, 24]. Such an accuracy should not be a problem in open sea navigation but could present an issue during manoeuvring and docking a vessel. During manoeuvring and docking, it is advisable to use fixed objects at the shore to confirm vessel movement. Additionally, advanced terminals handling large tankers use a laser docking system, which provides the distance to the berth and approaching speed [44, 57].

3.1.3 *Gyro compass*

A gyrocompass is an equipment that determines the direction of the ship's head in relation to geographic (true) north [20]. Besides classic electromechanical gyrocompasses mostly found on the ships, some new technologies are commonly known as electronic compasses. Whatever type of compass being used for heading source to ECDIS, it is necessary to check it periodically to determine its error [38, 40]. Control of gyrocompass error is customarily done each watch, and after any major change of course, and observed error must be recorded in the gyro error book. This practice keep navigator familiar with traditional navigational routines, such as aligning two charted objects or observing azimuths and amplitudes of celestial bodies. Research by Lushnikov et al. conducted on merchant navy ships reveals negligence in controlling gyro error [45]. One of the prerequisites of a reliable ECDIS display is correct information input by sensors, and if gyro error is not frequently checked and monitored, it could lead to unreliable display on the ECDIS system.

3.1.4 *Radar*

After World War II, the radar's introduction in a merchant fleet has caused a new category of accident known as "radar assisted collisions" [52]. Expression was first used to describe the collision between Italian passenger ship Andrea Doria and Swedish liner Stockholm that happened on 25th July 1956. As overreliance on radar was a major cause of this accident, this was followed by mandatory training for the use of radar to become more systematized and widespread [46]. Except for its role as a collision avoidance tool, radar is useful as a device determining a ship's position in coastal navigation. Several methods by measuring bearings and distances from conspicuous fixed objects are available. Among others, the measurement of radar bearings and ranges from a single conspicuous object is a quick and effective procedure [8]. Additionally, to position fixing by a radar system, there is a Parallel indexing method, a method of cross-checking ship's path by monitoring line parallel with the ship's route, mostly used in confined waters. Finally, radar's significant advantage is the independence of external sources, as the system relies on its own detection of objects in the environment. However, its performance is affected by the meteorological conditions (clutter), false echoes, size, and material of detected objects and land features [38]. According to IMO performance standards, radar system range and bearing accuracy should be within than 1.0% of range scale used or 30 m, whichever is greater for range measuring, and within 1° for bearing measurement [25].

Modern ECDIS system is interfaced with radar, allowing duplication of radar image over the ENC. This possibility is called Radar Information Overlay (RIO). While radar image often has numerous distortions, including radial and angular distortions of the radar echo, several difficulties to detect systemic distortions [33], RIO is still the most immediate means of verifying ECDIS cartographic data and the output of navigation sensors [32, 54, 60]. Furthermore, the RIO advantage is real-time and efficient cross-checking, allowing OOW to detect a mismatch between radar echo and ECDIS data easily. A possible mismatch that can be revealed includes cartography errors, GPS/GNSS positional errors, and a Gyro heading error. Thus, RIO emerges as an efficient and valuable tool for cross-checking data obtained on the ECDIS system.

3.1.5 *Automatic identification system (AIS)*

AIS is an automatic reporting system designed to improve the safety of navigation, by exchanging vital navigational information between ships and between ship and coast station. AIS system could be interfaced with ECDIS system as an additional sensor and connected to both radar and ECDIS on many modern ships. There are several significant drawbacks of the system: many small ships are not equipped with AIS, it can be even switched off on ship's master judgment [23], or to cover illicit operations, causing the interruption of AIS reception [39, 47], the received reports can be unintentionally incorrect, jammed or deliberately spoofed [23, 39]. Overreliance on AIS as a sole navigational aid is extremely dangerous, as in the collision between Rickmers Dubai and Walcon Wizard. The investigation established that OOW on Rickmers Dubai was relying solely on AIS information displayed on the ECDIS as an aid to collision avoidance [36].

Considering all the above mentioned, AIS should be used as supplementary information only to information derived visually and by radar. In that case, when supplemented by other navigational aids, it can be an important 'tool' in enhancing situation awareness at sea [14, 23].

3.2 *Overreliance on chart data*

Recent groundings of Dutch freighter Nova Cura in 2016 and tanker Pazifik in 2018 serve as a reminder that chart data reliability even on state-of-the-art equipment is often questionable. Both ships run aground due to unreliable ENC data [11, 13]. ENC data reliability depends on the quality of chart survey data, which in many cases are outdated and based on a survey from the beginning of the last century. This mainly goes to remote areas of oceans, where low chart accuracy could be expected (Table 1). The ENC survey data's accuracy is expressed by the Zone of Confidence system (ZOC), developed by the International Hydrographic Organization (IHO). There are five basic levels within the system differing levels of quality, starting from "very high confidence" to "unsurveyed" [18].

Table 1. Analysis of 14 million square kilometres of coastal ENC [11]

Category	Area percentage of English Channel	Area percentage of Singapore & Malacca Strait	Area percentage of the world's coastal ENC	Confidence
A1	3.6%	1.4%	0.7%	Very Good
A2	9.4%	0.2%	1,0%	Very Good
B	62.9%	2.5%	30.5%	Good
C	21.3%	76.2%	21.8%	Fair
D	2.8%	1.1%	20.5%	Low
U	0,0%	18.5%	25.4%	Low

Large areas of the world are still poorly surveyed, reflected as some ENC's questionable accuracy. Overreliance on ENC as a sole source of information, without proper knowledge of the ZOC system, could result in an accident. Passage planning should include all sources of information available, including navigational publications but local knowledge as well where required. Needless to say, all information must be timely updated, not only ECDIS but all other sources of navigational information as navigational publications.

Additionally, there still exists some ENCs derived from PNCs that cannot be accurately referred to WGS84 datum, generally used by GNSS and ECDIS. Differences between positions obtained by the satellite system and position on this cell could be significant [61]. Mariner must always strive to cross-check position by all available means when sailing in this area.

4 PREVIOUS RESEARCH AND ECDIS EHO SURVEY METHODOLOGY

The risk of overreliance on ECDIS was recognized as an important safety issue a decade before its full implementation on merchant ships [27, 31, 62], and it is continuously emerging as a problem [2,48,63]. Several surveys from the early beginning of the ECDIS system's implementation period, conducted as a questionnaire among end-users, revealed that overreliance is considered by users themselves as a problematic issue. In [4] Asyali has shown the result of a study performed among 230 Turkish Officers and Masters between June 2008 and October 2011, which have indicated that main officers' objections with regards to ECDIS usage are danger of overreliance on ECDIS, overconfident and over relaxed officers, degradation of navigational skills, reliability of the system. Another survey [30] by Karnicnik conducted between March and April 2005 aimed at officers' opinion on using electronic charts. Results revealed that officers consider overreliance on ECDIS as a severe disadvantage. Research [5] by Bakalar et al., among 69 experienced navigators, reveals a similar result, as respondents clearly said that ECDIS's use degrades navigation skills and makes navigators indulgent. As recent years have been marked with a sequence of marine accidents that indicated ECDIS as a contributing element, several researches which analyzed mentioned accidents indicated overreliance on ECDIS as a contributing factor to the accident. In [1], Acomi analyzed several ECDIS-related maritime accidents and have recognized that the causes of accidents are results of overreliance on the system. In a recent paper [59], Turna et al. used the 4M Overturned Pyramid (MOP) model to analyze twenty-two accidents related to ECDIS or ENCs and have recommended that officers should cross-check information obtained by ECDIS by other navigational methods.

Overreliance on ECDIS as an essential issue was recognized by ECDIS EHO research through different surveys of navigators' interaction with the system. In [9], Brcic et al. studied the handling of the ECDIS system by end-user. Over 500 marine accidents were processed, and accidents related to ECDIS were analyzed. Results have shown overreliance on ECDIS as a significant factor in analyzed accidents, while improper ECDIS use is pervaded through all the cases. ECDIS acceptance after the completion of the implementation period, as seen by Masters, was in the focus of research [10] by Brcic et al. Among several key points, there is a problem of overreliance, decisively emphasized by masters, as most experienced persons on board. In [8], Brcic et al. dealt with the ECDIS system's positioning and reliable secondary positioning source usage. Overreliance on technology was identified as an important issue together with non-usage of ECDIS secondary positioning source and other issues arising from the transition period. Again, overreliance as a serious problem is recognized in research [6] conducted at the end of the ECDIS transitional period. Finally, as improvements of the education process and training activities have been in the focus of the ECDIS EHO project since beginning in 2014, the matter of proper education and training with regards to the system including excessive reliance on it has been raised in previous researches [6, 64].

The survey initially arose as a questionnaire distributed among attendees of ECDIS courses in the year 2014. The data were collected internationally until 2018 and impart insight into various issues regarding ECDIS implementation on board merchant navy. There are three types of questions contained in the questionnaire. Introductory questions serve to profile respondents according to their rank, seagoing and ECDIS experience, and ECDIS education level. The second set of questions is related to the handling of the system with a particular focus on navigation safety. Finally, the opinion of navigational officers on ECDIS benefits and shortcomings is covered by the last section of questions. ECDIS EHO research from the beginning aimed at educational improvement by analyzing specific topics pertaining to the project's theme. Navigational officer as end-user is in a central point of research, providing feedback, generating findings, and sometimes showing different perspectives on the subject. This paper simultaneously analyses two closely related questions regarding confirmation of the accuracy of information displayed on ECDIS and experience with position mismatch on the ECDIS system. Among all information sources connected to ECDIS, GNSS as a positional source requires the most attention. It is due to its vulnerability, history of overreliance, and insufficient redundancy. Insight about officers' confirmation methods and practice to avoid dependence on ECDIS as a sole navigational aid and their experience with position reliability on ECDIS is given by an analysis of the following questions:

1 1. Have you encountered position mismatch/offset/error or any other problem related to position display on the ENC? If YES, please explain the case/s.(Q1)

2 2. What is the best confirmation of the accuracy of information displayed on the ECDIS system (circle and, if you think it is relevant, write and explain the answer)? a. Radar; b. Visual observation; c. Something else. (Q2)

Q1 consists of two parts. In the first part, besides YES/NO answers, a N/A (not applicable) answer has been introduced for ambiguous or blank answers. The second part of Q1 clarifies positive answers, which could be further categorized and elaborated.

Q2, as an answer, offers a choice of Radar, Visual, or another method of accuracy confirmation. Respondents have had the opportunity to explain the answer closely, which is further elaborated.

5 RESULTS

The International EHO Survey contains responses from 350 respondents: 99 Masters (M), 77 First mates (1/O), 66 Second mates (2/O), 13 Third mates (3/O), 8 Staff captains (SC), 1 Marine safety consultant (MSC), 3 Safety officers (SO), 3 Environmental officers (EO), 4 Dynamic positioning operators (DPO), 1 pilot (P), 1 superintendent (SI), 1 supervisor (SV), 14 port State control officers (PSCO), 25 trainees (T), 1 Yacht-Master (YM) and 33 persons of unspecified position making part of the navigational watch (U) (Figure 2).

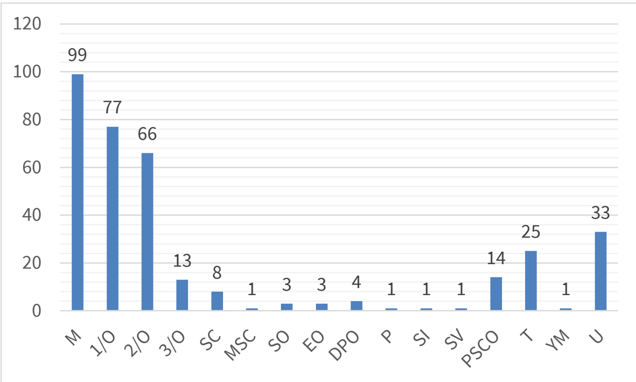

Figure 2. All ECDIS EHO survey respondents

As a subject of this paper is the overreliance of active users of the system, it was required to filter respondents to a representative sample. Filtering was done by using introductory questions, which were used to distinguish the target group from the initial sample (Figure 3). In the first stage (FS) of the survey, respondents with no ECDIS experience were removed from the sample. In the second stage (SS) other ranks except for Master, Staff Captain, First Officer, Second, Third Officers, and Trainees were excluded, as well as a respondent with missing data with regards to profile-defining introductory questions. In the third stage (TS), respondents whose job profile does not include working with ECDIS were excluded as well. Finally, it gave us a total of 208 respondents who are actively using ECDIS and have previous experience with the system.

Finally, it gave us a total of 208 respondents who are actively using ECDIS and have previous experience with the system. Shares of target group respondents according to their rank is presented in Figure 4.

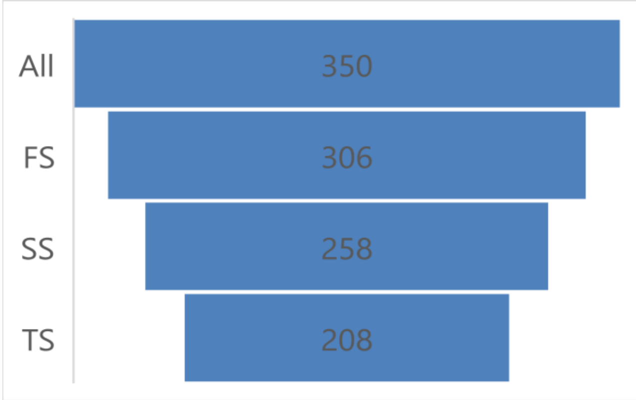

Figure 3. Target group selection stages

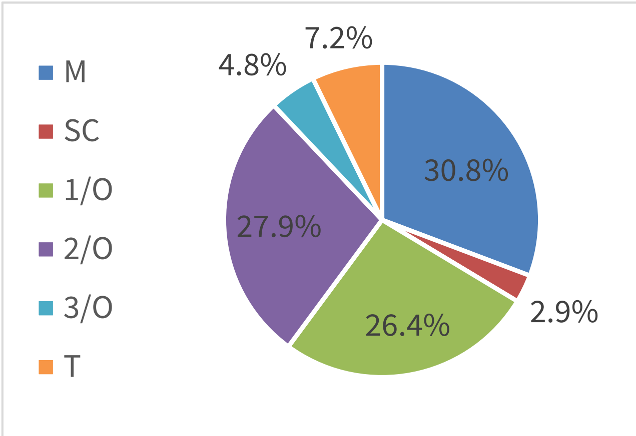

Figure 4. Target group respondents' shares

The general share of answers on the first part of Q1 is shown in Figure 5. Most respondents did not experience position mismatch on ENC (48%); however, the share of respondents that encountered position error is remarkably high (37%).

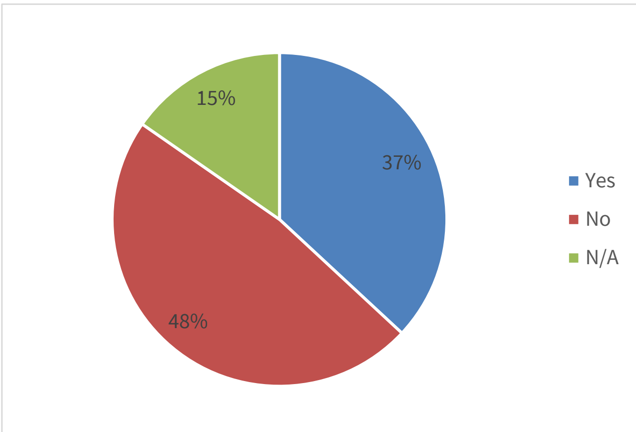

Figure 5. General share of answers (Q1 – first part).

Analysis of the second part of Q1 deals with respondents that positively answered the first part of the question. Circumstances behind experienced problems with regards to position display on ENC are clarified in this part (Figure 6). Comments are clustered into four groups that are based on typical answers from respondents:

- Offset determination method
- Offset cause
- Offset geographic area
- Unclear

The offset of position is possible to determine by comparing ECDIS primary position obtained by GNSS and ideally secondary independent source, or by position plotted using LOP obtained visually, by radar or another available mean. Additionally, offset could be recognized by comparing ENC cartography with RIO, but the exact value cannot be determined without position fixing. The offset cause could be a result of sensor error or cartography issue. The offset geographic area provides details of the area where the error occurred. Some respondents even providing a positive answer to the first part of Q1, did not provide any explanation in the second part. These answers are gathered into section Unclear, together with indefinite answers. In comparison, some respondents explain the case by the method of offset determination; other states possible causes of the incident or area where the incident occurred. Furthermore, some respondents provided answers belonging to more than one group.

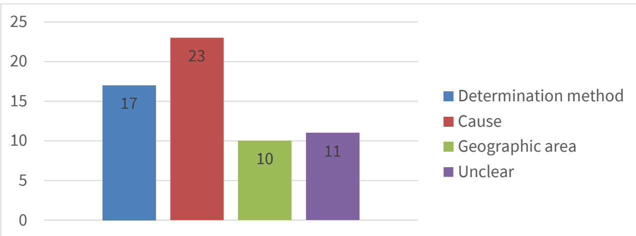

Figure 6. General share of answers (Q1 – second part).

Each group of comments is further analyzed (Figure 7). Analysis discovers that respondents explaining the method of offset determination have mostly used radar (53%), while from the rest of the answers, it is not clear what method was used to recognize offset. The major share of respondents that mentioned cause of offset identified chart accuracy or wrong datum as a cause of position offset (39%), followed by Lost GPS signal (35%) and GPS & Gyro error (17%). Among respondents that identified the incident's geographical area, most of them experienced that issue in South America (40%) followed by other areas.

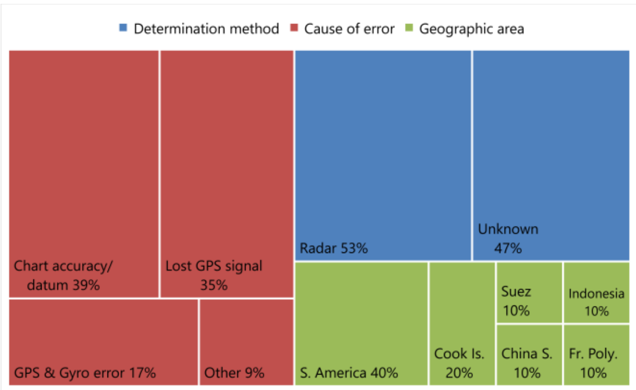

Figure 7. Answers' categories on the cause, determination method, and geographic area (Q1 – second part).

Figure 8 shows the general share of answers to Q2. Results clearly illustrate almost the same percentage of answers between radar (31.7%) and visual (30.8%) confirmation of information displayed on ECDIS. Active users of the system find both options equally valuable. Interestingly the roughly same percentage of respondents choose a combination of radar and visual confirmation (30.8%) as their choice, even the question was to specify the best method.

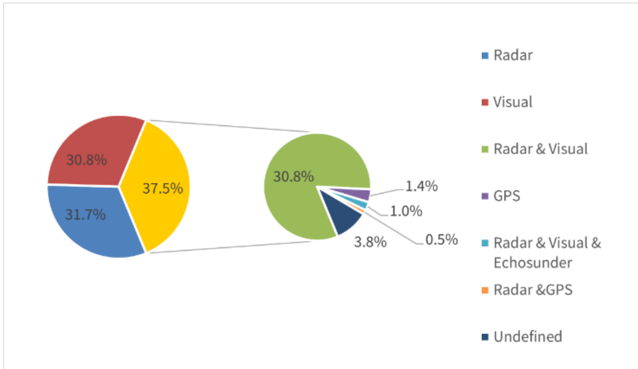

Figure 8. General share of answers on Q2

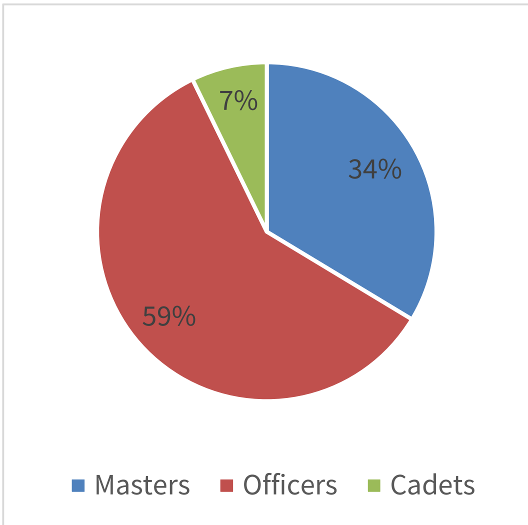

Figure 9. Target subgroups' shares

Logically best method can be only one, but clearly, navigators cannot decide which method is better or find them complementary. These two methods, alone or combined, give 93.3% of answers. Other answers with minor frequency include confirmation by GPS (1.4%), radar, visual and echosounder (1.0%), radar and GPS (0.5%), and undefined answers (3.8%).

Furthermore, to get a better insight into the survey, the target group was divided into three major subgroups: Masters (include Masters and Staff Captains), Officers (include Chief Officers, 2nd Officers, and 3rd Officers), and Cadets (Figure 9).

Methods of confirmation of accuracy are the same as above: radar (R), visual (V), Radar & Visual (R&V), GPS, Radar & Visual & Echosounder (R&V&E/S), Radar and GPS (R&GPS), Undefined (U). The result reveals differences and similarities between subgroups (Figure 10). While Masters prefer radar more than visual, officers declare both methods equally important. The cadets' group has significantly less confidence in radar as a source for cross-checking compared to the other two groups and equally choose visual confirmation and a combination of radar and visual.

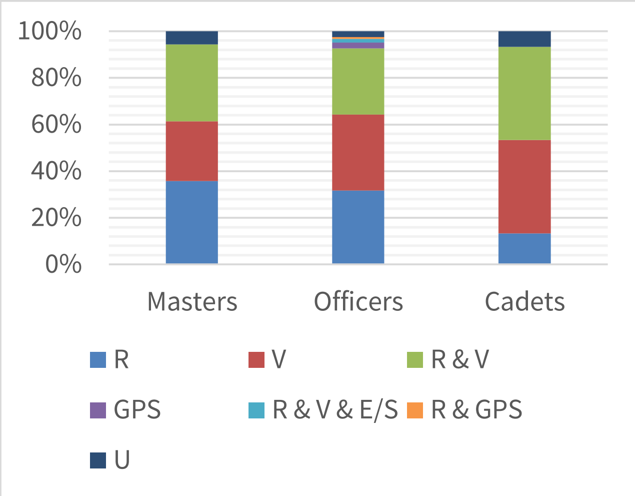

Figure 10. Results on Q2 for target subgroups

It is important to note that all three groups have almost the same percentage for the sum of the first three methods, i.e. radar, visual, and radar and visual methods.

6 DISCUSSION

Considerable problem is revealed by results of Q1, showing a significant share of respondents that have encountered a problem with position mismatch on ECDIS. As much as 37% of respondents experienced a serious near miss, which can cause a catastrophic accident. Position error was observed using a radar in 53% of cases, proving that radar and RIO are the most favoured method of cross-checking. Significantly, for the remaining 47% of answers, it is not clear what method was used to recognize offset, so there is a possibility that shares of errors observed by radar are even larger than 53%. Detailed analysis of offset causes discovers that more than a half respondent (52%) explaining the cause of the offset mentioned GPS as a source of trouble. This is expected as GPS is the main source of position information to the ECDIS system. This fact particularly emphasizes the need for ECDIS secondary position source other than GNSS. The major group (39%) mentioned chart accuracy or wrong datum as the cause of position offset. Results on Q1 stress the necessity of frequent cross-checking of ECDIS information, especially in the coastal area, where routine navigational methods are easily available. All three significant causes of position offset are easily recognizable by position cross-checking and using a visual and radar confirmation, but only in the coastal area. Answers do not provide information if any of the position mismatches were detected at the open sea. Results of Q2 recognize radar (31.7%) as a preferable system, closely followed by visual confirmation (30.8%) and a combination of radar and visual (30.8%). A minor number of participants mentioned other methods, such as GPS and echosounder. As GPS is the main source of positional information to ECDIS, it makes no sense to control ECDIS by GPS. Echosounder is one of the possible methods, but hardly the best one. None of the respondents mentioned astronomical navigation as a possibility to assess the accuracy of ECDIS information at the open sea.

Among all groups, Masters, as the most experienced group, prefer radar significantly over visual observations, which is in line with the research of Šakan et al. (2018) [50]. Cadets, as the least experienced group, evaluate the visual method with the highest rank. Officers, as the most represented group, find both methods equally important. It seems that radar preference goes hand in hand with experience. Finally, Q2 provides a valuable outcome, as, despite the question which was targeting the best method of confirmation, a significant number of respondents choose a combination of methods. Clearly, the system's active users are aware of the necessity to check position by all available means available. Indeed, no method is perfect, so a combination of methods to establish situational awareness is good seamanship practice.

Nevertheless, the results of Q1 with regards to the actual offset determination method where most of the respondents that explained their experience used radar to cross-check position on ENC does not fully support answers from Q2. When asked about the best method of confirmation, the same respondents choose radar and visual observation as almost equal, but none of the actual discoveries of position offset in Q1 was by visual method, or it was not clearly mentioned. Does it mean that even respondents consider both methods equally good, prefer using radar confirmation in practice due to its feasibility? Social-desirability bias is another explanation, i.e., respondents may tend to give answers which are more acceptable to the community. In the case of Q2 visual observation is a favourable answer as it is considered a prime navigation technique. In fact, radar cross-checking is a more practical method, providing instant information on possible presentation errors. Visual observation is generally less practicable than radar observations except in narrow spaces like port areas or channels.

Several findings were observed:

- Position error is a frequent occurrence. Fortunately, it can be detected in coastal navigation by using available traditional cross-checking methods.
- Position error is mostly noticed by the usage of radar.
- Visual and radar confirmations of ECDIS information accuracy are equally graded cross-checking methods, but it seems that users in practice detect anomalies by radar usage.
- Experienced navigators favour radar over visual observations for confirming ECDIS information accuracy.

Considering identified observation, a conclusion is that radar is a navigational instrument mostly used to assess ECDIS information accuracy, despite its constraints. The conclusion further highlights the necessity of ECDIS secondary position source such as a hyperbolic navigational system, which would significantly improve the confidence in the ECDIS system.

A flow diagram showing the progression of positional error is presented (Figure 11). Positioning errors affecting situational awareness could be categorized as system errors and human errors. While system errors result from sensor error, ENC cartography, or poor bridge layout, human errors are affected by the experience, training, knowledge, and navigational skills. By cross-checking, possible errors are confirmed, rectified, and situational awareness is established once again. Poor or no cross-checking at all leads to overreliance, perilous situations where the navigator has a dull sense of control over the situation, while in fact, control over the ship is lost.

Cross-checking is the most important way to control overreliance and hold a grip on situational awareness, but it should be done with all available means, not relying on one method only. Raising awareness among navigators through educational activities to keep them always positively suspicious is crucial. Recognizing own and system limitations actively raise navigator's awareness, counteract overreliance, and positively affect the safety of navigation.

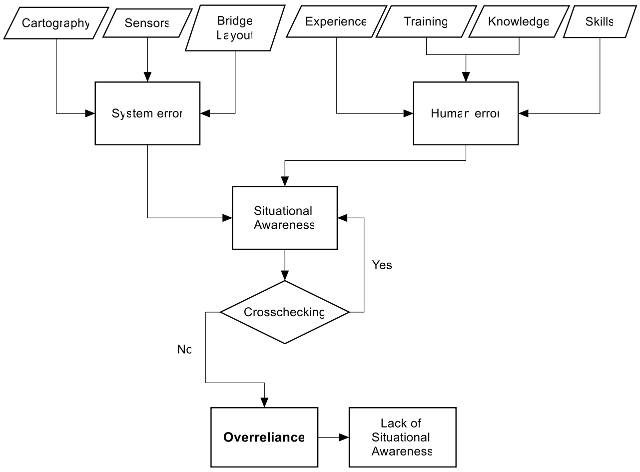

Figure 11. Flow diagram of overreliance effect on situational awareness

7 CONCLUSIONS

The proposed paper deals with an overreliance on information obtained by the ECDIS system, specifically on information obtained by position source. The survey is supported by the international questionnaire. The questionnaire was conducted in the period from 2014 to 2018, during the second half of the ECDIS implementation period. The research aimed to identify the frequency and details of wrong position indications on ECDIS and the preferable ECDIS information cross-checking method. The answers from the target group were analyzed and discussed. The findings indicated that the position error on the ECDIS system is relatively frequent, which entails potential high risks regarding navigation safety. According to answers, GPS errors are the leading cause of position deviations on ECDIS, which is expected considering that GPS is the primary source of position data to ECDIS.

Confirmation of ECDIS information accuracy or cross-checking is performed by radar, visual observation, or other available navigational means. While visual and radar methods are almost equally rated methods for confirming the accuracy of the information, answers revealed that in practice, radar is used more to detect deviations. Moreover, more experienced navigators prefer radar over visual observation. Despite obvious radar advantages in terms of practicality, there are still some limitations of the radar system that navigator must recognize. A desirable solution to overcome ECDIS positional accuracy failures could be a secondary position source other than GNSS.

The fact that a significant number of respondents are choosing more than one method to confirm the accuracy of information denies degradation of navigational skills so far. Educated and experienced navigator stay alert even when everything looks perfect and recognize the appropriate cross-checking method depending on circumstances. Considering the abovementioned, a key answer is a proper educational framework customized for new generations of navigators handling new technologies. By using cross-checking, the navigator can detect eventual errors, rectify them, and gain situational awareness. Contrary, without cross-checking, the navigator becomes over-confident on instruments, and consequently, situational awareness is lost.

Future work will consider other significant ECDIS information sources that could affect situational awareness by over-relying on them.

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