Application and usability of

# ECDIS

A MAIB and DMAIB collaborative study on ECDIS use from the perspective of practitioners

# CONTENT

# GLOSSARY OF ABBREVIATIONS

| | |
|---|---|
| 1/0 | First officer |
| 2/O | Second officer |
| 3/O | Third officer |
| AHO | Australian Hydrographic Office |
| AIO | The admiralty information overlay |
| AIS | Automatic identification system |
| ARPA | Automatic radar plotting aid |
| ATSB | Australian Transport Safety Bureau |
| BAM | Bridge alert management |
| C/O | Chief officer |
| CATZOC | Category Zone of Confidence |
| DMAIB | Danish Maritime Accident Investigation Board |
| EBL | Electronic bearing line |
| ECDIS | Electronic chart display and information system |
| ECS | Electronic chart system |
| ENC | Electronic navigational chart |
| ETA | Estimated time of arrival |
| GLONASS | Global navigation satellite system |
| GNSS | Global navigation satellite system |
| GPS | Global positioning system |
| HO | Hydrographic office |
| HSC | High speed craft |
| ICS | International Chamber of Shipping |
| IEC | International Electrotechnical Commission |
| IHO | International Hydrographic Organization |
| IMO | International Maritime Organization |
| INS | Integrated navigation system |
| INTERTANKO | International Association of Independent Tanker Owners |
| ISO | International Organization for Standardization |
| LNG | Liquified natural gas |
| LOP | Line of position |
| MAIB | Marine Accident Investigation Branch |
| MFD | Multi function display |
| NAVTEX | Navigational telex |
| NCSR | IMO Sub-Committee on Navigation, Communications and Search and Rescue |
| OCIMF | The Oil Companies International Marine Forum |
| OOW | Officer of the watch |
| PSC | Port State control |
| RIO | Radar image overlay |
| SENC | System electronic navigational chart |
| SMS | Safety management system |
| SOLAS | International Convention for the Safety of Life at Sea |
| STCW | International Convention on Standards of Training, Certification and Watchkeeping for Seafarers |
| T&P | Temporary & Preliminary [Notices] |
| UKC | Under keel clearance |
| USB | Universal Serial Bus |
| VRM | The variable range marker |
| WGS | World geodetic system |
| XTD | Cross track distance |

# EXECUTIVE SUMMARY

## BACKGROUND

In investigations of groundings since 2008 in which ECDIS were the primary means of navigation, MAIB and DMAIB identified a mismatch between the way ECDIS was used and the intention of performance standards and system design. This prompted the MAIB and the DMAIB to study ECDIS use from the perspective of practitioners. The aim of the study was to generate an understanding of the practical application and usability of ECDIS and support future ECDIS design, training strategies and the development of best practices. The study followed a qualitative methodology, primarily based on semi-structured interviews with 155 ECDIS users and observation data gathered between February and July 2018 during sea voyages in European waters on 31 ships of various types.

## FINDINGS

*Spectrum of use*

ECDIS use was contextual across a wide spectrum with practices dependent on type of ship, ship trade and area of operation. This included ECDIS status (primary means of navigation, back-up or navigation aid); ECDIS type (model/number/age) and level of integration with other equipment; bridge layout and ergonomics; user familiarity and knowledge of the system; user experience; bridge manning and organisation; on board procedures; trading patterns; masters' preferences and level of exposure to port state control, vetting and audit.

At one end of the spectrum of ECDIS use were paperless ships with a high level of bridge system integration with purpose designed 'cockpit-style' bridge layouts, multiple ECDIS and multi-function displays (MFD) integrated with sensors and systems via a data highway. At the other end of the spectrum of ECDIS use were ships with a stand-alone ECDIS.

Within the spectrum of ECDIS use, some ships continued to carry paper charts in addition to ECDIS, increasing the navigators' workload as both media required correction/updating. In some cases, passage plans had to be drawn on the charts as well as input to the ECDIS. Where paper charts were the primary means of navigation, and ECDIS was a 'navigation aid' or for 'training purposes only', ECDIS was used as the principal tool for navigation, but its safety features, such as the lookahead, were often ignored. In effect, paper chart use was a compliance activity, limited to the periodic plotting of positions 'for the record'.

*Overall benefits*

Users identified the ECDIS' main contributions to safe navigation as the reduction in workload and the increase in situational awareness resulting from real-time positioning. ECDIS' reliability and the integration of ECDIS with other navigational systems were also seen as benefits. Given that the various sources of information are usually accurate, and the users rarely experienced malfunctions, they were generally found to trust the information provided by ECDIS and its technical reliability.

Some ECDIS functionalities were seen to reduce the manual labour of updating charts, plotting routes using waypoints, etc., but these functionalities were not necessarily viewed as contributing to safe navigation per se.

Noticeably, the users who had experience working with paper charts specifically pointed to the reduction of workload of manually plotting the ship's position as the main advantage of the ECDIS, because it freed up time to focus on other safety critical tasks, e.g. route monitoring and collision avoidance. A majority of users found this functionality to be the most beneficial system functionality of the ECDIS, because of the time saved. Presumably, the time gained is used for improvement of the cognitive assessment of the navigational situation, i.e. more time for route monitoring, keeping lookout, analysing the traffic situation, verifying the position by other means, interacting with the pilot, etc. Thereby, the user can make more informed decisions about collision avoidance, manoeuvring the ship, etc. From the user perspective, having more time to assess the navigational situation thus becomes the ECDIS' main contribution to safe navigation.

### *Challenges*

This study showed that while the standardisation and allocation of simple and repetitive tasks (plotting the ship's position and chart update) has brought about tangible benefits, the required user interaction with ECDIS has introduced challenges that cut across system design, practices and training. These challenges include:

- The distraction of alerts and alarms, particularly during pilotage, that leads to coping strategies ranging between alarm 'normalisation' and physical disablement.
- The frequent impracticality of the setting of an efficient safety contour, leading to the use of 'official workarounds' (e.g. included in recognised guidance) and 'unofficial workarounds' (e.g. alarm disablement) to optimise the display to make the best of a bad job. Alternatively, the safety contour is ignored altogether.
- The number and types of alerts generated during automatic route checks that leads to them either being ignored or increases the risk of planners missing safety critical alerts among numerous more trivial ones.
- Interfaces and menu complexity that increase cognitive workload, particularly in busy environments, which results in users focusing on ECDIS to the detriment of other sources of information.
- The difficulty of residual manual tasks such as planning radar parallel indices, plotting limiting danger lines or writing text notes, which are often time-consuming, deters users from their application.
- ECDIS requires significant cognitive resources to use its functions, which has contributed to a minimalist approach by users.
- ECDIS use continues to be framed and audited within the context of paper chart practices with Flag State, PSC and SIRE inspections often not recognising new ways of working such as the use of radar information overlay to verify position.
- Users are trained to distrust the ECDIS and continuously verify the ship's position by alternative means. However, significant discrepancies are rarely encountered.

## CONCLUSION

From a user perspective, ECDIS does contribute to safe navigation, but the challenges that have accompanied its introduction are problematic. Some of these challenges stem from the system's automation not always working efficiently due either to the lack of bathymetric fidelity i.e the provision of depth contours in the same manner as provided on paper charts and/or human-centred design not being considered. Decisions to automate and 'alarm' the safety contour seem to have been based on the technical ability to do so rather than on an adaptable blending of human and machine capabilities to complete identified tasks in differing scenarios and environments.

Other challenges seem to stem from industry inertia with ECDIS being viewed in the same way as paper charts, i.e. a homogenous work process requiring a uniform skill set across different ships and trades. However, ECDIS is not a standardised and automated paper chart. It is a technology that provides a new form of situated knowledge by contextualising information from various sources, providing a different perspective on the navigational situation. ECDIS has expanded the bridge watchkeeper's role in maintaining the safety of a vessel by increasing the data available that requires management, assessment and interpretation. It has also made navigational practices heterogeneous, necessitating different types of training, proceduralisation and technological solutions.
Although ECDIS use has been incorporated to some degree in the relevant conventions, the 'best' practices cited by many remain those often associated with paper charts with paper chart practices remain at the heart of navigation training in nearly all maritime colleges worldwide. As ECDIS proliferates, and ECDIS-related practices and skills develop, it seems impossible that such a strategy can continue.

## WHAT NEXT?

The findings of this study identify many of the problems ECDIS users experience with the system at sea today, and in the short-term it is the ambition of the DMAIB and MAIB to engage with ECDIS stakeholders to try to effect the changes required to improve ECDIS performance through better bathymetry along with changes in design and training. However, the findings also point towards deep-rooted, structural flaws in the way that new navigation technologies are implemented. Flaws that continue to hinder system development and the evolution of new ways of working, and which also promote reactive rather than proactive approaches in many areas.

Addressing such key issues will challenge traditional thinking and structures. It will also require international liaison and agreement. Although no recommendations have been made it is hoped the study will serve as a catalyst for change by the maritime industry to ensure that, among other things:

- The principles of human-centred design are followed.
- User experience is captured and acted upon both in terms of system functionality, training, and practices.
- Core navigation training truly reflects the dominant use of ENCs compared to paper charts and the changed role of the OOW brought about by automation.

From an accident investigation perspective, DMAIB and MAIB will present and discuss the study with other AIBs with a view to sharing the benefits of qualitative research and influencing how accidents involving interaction between the user and complex technological systems, such as ECDIS, are investigated.

## ACKNOWLEDGEMENTS

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# INTRODUCTION

# INTRODUCTION

Since 2008, the UK Marine Accident Investigation Branch (MAIB) investigations of groundings in which Electronic Chart Display and Information Systems (ECDIS) were the primary means of navigation identified that the ways the vessels' ECDIS were configured and utilised had been contributory (see Table 1 in the appendix). There was a mismatch between the way ECDIS was used and the intention of performance standards and system design. Common themes included passages being planned across unnavigable water, voyage plans not being adequately checked visually or using the automatic route check function, safety settings not matching the navigational context, and audible alarms being disabled. Consequently, the knowledge and performance of the officers of the watch (OOW) were called into question.

However, there was also evidence to suggest that the ECDIS did not fully meet the needs of the end-user, and more recent accident investigation reports have identified issues related to the fidelity and presentation of the underlying hydrographic data.

In 2018, the MAIB and the Danish Maritime Accident Investigation Board (DMAIB) agreed to investigate ECDIS use from the perspective of practitioners based on the hypothesis that it was a combination of both usage, continuous development and design issues that contributed to the recurring difficulties surrounding ECDIS use.

The aim of the study was to generate an understanding of the practical application and usability of ECDIS that would benefit future ECDIS design, training strategies and the development of best practices.

# METHODOLOGY

Insufficient granularity and consistency in marine accident databases precluded any meaningful quantitative analysis of 'ECDIS-related' accidents. Furthermore, as only the marine accidents with significant consequences tend to be investigated, it was not possible to gauge the extent to which the contributing factors identified in the accident reports referred to in this report were common or whether the circumstances of these accidents were outside usual practice. Consequently, to gather a broad perspective of how ECDIS was being used in differing contexts, the views of various stakeholders, particularly the users, were sought.

The MAIB and DMAIB study was primarily based on interview and observation data gathered between February and July 2018 during sea voyages on 31 ships of various types. These included cruise ships, tankers, bulk carriers, container ships, ferries, High Speed Craft (HSC) and service ships. During these voyages, which were up to 4 days in duration on ships operating in European waters, 155 ECDIS users were interviewed, comprising 24 nationalities, and the use of ECDIS from eight different manufacturers was observed. The ages of the users varied from 21 to 62 years, and participants were spread evenly over the range. All but 4 of the ECDIS users were male.

The framework for the semi-structured interviews comprised open questions on ECDIS themes such as; advantages and reliability, disadvantages and unreliability, functionality, contribution to safe navigation, near misses and automation surprise[1], design, competency and training.

1 Situations where the operator is surprised by the behaviour of the automation asking questions like: "What is it doing now?" or "Why did it do that?" or "What is it going to do next?".

Role specific questions were also put to masters and users responsible for passage planning in order to gain an insight into ECDIS use from these perspectives. Each interview lasted on average between 45 minutes and 1 hour. Following review of the interview data it was clear that saturation had been reached for all aspects of the interview schedule and further interviews were unlikely to produce novel insights.

The data from the interviews and observations was analysed to identify themes in an objective and unbiased way. The purpose was to identify themes connected with ECDIS' contribution to safe navigation and difficulties with use. User responses were analysed to determine dominant themes using NVivo qualitative data analysis software. Confirmation and theory biases were managed by the MAIB and DMAIB analysing the responses independently. Some interviews were hampered by language difficulties, so extra care was taken to confirm responses were appropriate to the question being asked.

A spectrum of ECDIS use was identified with differing practices dependent on type of ship, ship trade, area of operation, ECDIS type and other tangible variables. As the data gathered during the study was highly contextual, no quantitative analysis was attempted.

Interviews were also conducted with 15 UK and Danish deep-sea pilots, 13 ship managers and ship operators, five ECDIS manufacturers, ECDIS trainers and representatives of the hydrographic and technical communities to gain insight into their views on ECDIS development, use and training. The findings of published accident investigation reports, applicable International Maritime Organization (IMO) and International Hydrographic Organization (IHO) documents, International Electrotechnical Commission (IEC) technical standards, and academic papers and industry articles connected with ECDIS use were also reviewed and referenced.

# THE REPORT

The intended readership of this report comprises a range of groups, including cruise line operators, shipping companies, maritime training institutions, authorities and legislators, affording them a detailed view of the everyday operations surrounding ECDIS use.

Headline feedback on the study's findings was provided at the IMO Sub-Committee on Navigation, Communications and Search and Rescue (NCSR) in January 2019, as well as through industry working groups, seminars and conferences. This report represents a more complete analysis of the data collected and emergent themes concerning ECDIS use. To make the findings of this study accessible and understandable to a wider audience, a discursive approach using as plain language as possible, has been taken.

The report is organised as follows:

**Part one** introduces how the use of ECDIS is contextual depending on a variety of tangible variables which influence the characterisation of the user views and observations presented in this report.

**Part two** begins with a description of how the IMO performance standards have an imbedded view on how the ECDIS contributes to safe navigation. The users' views on how ECDIS contributes to safe navigation is then presented and discussed.

**Part three** describes and discusses the users' perspectives on how ECDIS has brought about emerging challenges to users and their navigational practices.

**Part four** describes the users' perspectives on training and familiarisation and discusses how the users are prepared to meet the new challenges introduced by ECDIS.

**Part five** briefly describes how ship operators experience the emerging challenges of ECDIS.

**Part six** presents high level conclusions from the discussions and pathways to improvement of ECDIS.

# 1 SPECTRUM OF USE

# SPECTRUM OF ECDIS USE

The study identified a spectrum of ECDIS use with differing practices dependent on geographical context (open, coastal or confined waters) and other tangible variables. These included: ECDIS status (primary means of navigation, back-up or a 'navigation aid'); ECDIS type (model/number/age) and level of integration with other equipment; bridge layout and ergonomics; user familiarity and knowledge of the system; user experience; bridge manning and organisation; on board procedures; trading patterns; masters' preferences and; level of exposure to port state control, vetting and audit.

At one end of the spectrum of ECDIS use were paperless ships (e.g. HSC, modern cruise ships) with a high level of bridge system integration with purpose designed 'cockpit-style' bridge layouts (Figure 1), dedicated seated control stations and multiple ECDIS and MFD integrated with sensors and systems via a data highway. ECDIS were also sited remotely in locations such as the master's cabin.

Users on these paperless ships viewed ECDIS as just one component of the wider 'bridge system' with voyages being monitored using automatic radar plotting aid (ARPA) radar with a chart underlay. Bridges were routinely manned by two officers, both of whom had been familiarised with the bridge system (post generic ECDIS training) using 'in house' full mission bridge simulators and working to company procedures. The simulators were also used to develop navigation practices and bridge resource management techniques. Onboard procedures were ship specific and included forms for under keel clearance (UKC) calculation and guidance on ECDIS settings on the various voyage phases. Passage planning was conducted by a first/chief officer, supported in associated tasks, such as chart supply and update by other officers. Passage plans were sent to management ashore, who monitored voyages remotely. System resilience was provided through multiple ECDIS and having trained electro-technical officers onboard capable of diagnosing/resolving system problems. Manufacturer support was also available.

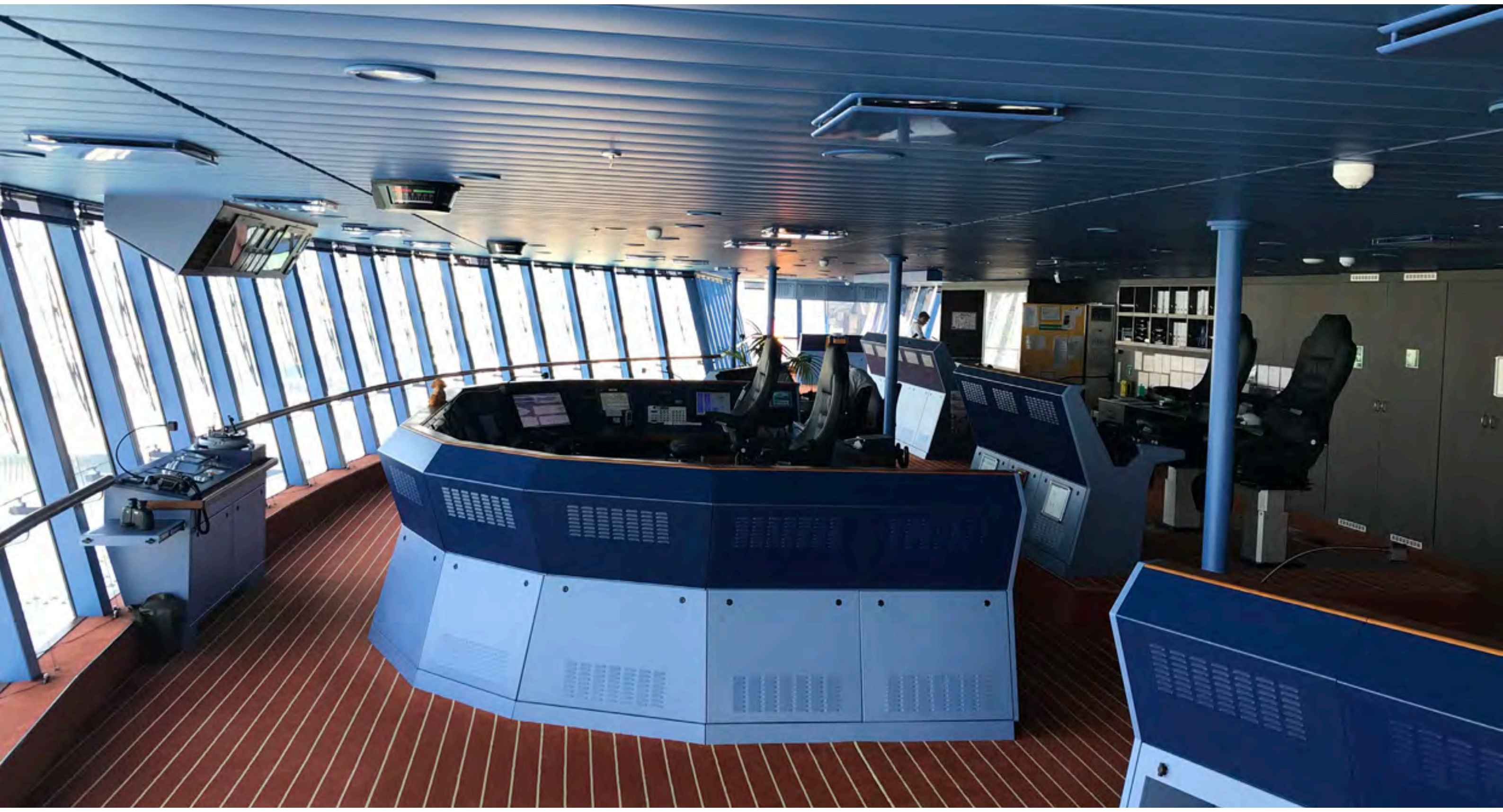

*Figure 1: Bridge layout on a modern cruise ship*

At the other end of the spectrum of ECDIS use were ships (e.g. ferries, bulk carriers), including new-builds, with a stand-alone ECDIS (Figure 2). The positioning of retro-fitted ECDIS was usually dependent on the space available and typically left to the preference of the technical superintendents and masters. Frequently, this resulted in the primary (monitoring) ECDIS being at the front of the bridge and the 'back-up' (planning) ECDIS by the chart table at the back of the bridge. Other than the Automatic Information System (AIS), the ECDIS had only the mandatory input from sensors required by standards. The layout required OOWs on these vessels to move around. They had completed generic ECDIS training, but the requirement for familiarisation training tended to be met through either on-board checklists, computer-based training or short shore-based courses. Onboard procedures had been modified from those used for paper chart navigation and were generic in nature. Passage planning was carried out by a second officer (2/O). System resilience was provided either by a single 'back-up' ECDIS, the carriage of paper charts and/or by having access to manufacturer support ashore.

*Figure 2: Bridge layout on a cargo ship*

Within the spectrum of ECDIS use, some ships continued to carry paper charts in addition to ECDIS, reflecting a reluctance by some ship operators to commit to paperless navigation. Study data, supported by an Oil Companies International Marine Forum (OCIMF) and International Association of Independent Tanker Owners (INTERTANKO) online survey of their members during 2019, showed that the simultaneous carriage of paper charts and ECDIS increased the navigators' workload with both media requiring updating. On board ships where paper charts were the nominated 'back up' for the ECDIS, passage plans also had to be drawn on the charts as well as input to the ECDIS, which further increased the workload. Where paper charts were the primary means of navigation, and ECDIS was a 'navigation aid' or for 'training purposes only', ECDIS was observed to be used as the principal tool for navigation, but its safety features, such as the lookahead, were often ignored. In effect, paper chart use was a compliance activity, limited to the periodic plotting of positions 'for the record'.

The focus on the spectrum's extremes is not meant to imply that navigation at one end of the spectrum is 'safer' or 'better' than at the other. The extremes are just different, with most ECDIS use occupying the middle ground with various combinations and permutations of the factors identified, which made it impossible to define a single characterisation of ECDIS use.

# 2 ECDIS USAGE & SAFE NAVIGATION

# INTRODUCTION

Amendments to the International Convention for the Safety of Life at Sea (SOLAS) which came into force in 2011 mandated the carriage of ECDIS for ships on international voyages. ECDIS carriage thus became compulsory for various vessel types and sizes subject to a staged entry into force between 2012 and July 2018. For ECDIS to satisfy carriage requirements, it must meet certain specifications. The ECDIS must be type-approved and meet IMO performance standards[2].

The IMO performance standards state that the primary function of the ECDIS is to contribute to safe navigation, but they do not explicitly state how the systems should achieve this goal. However, the performance standards mention two main qualities, which the system should deliver, that implicitly contribute to navigational safety: reliability and functionalities to reduce the user's workload including the integration of the ECDIS with other bridge systems.

*Reliability* is obtained by the system displaying chart information from a government authorised hydrographic office (HO), which can be reliably updated, and adequate back-up arrangements, i.e. system redundancy in terms of hardware, software or even paper charts. In a situation where the equipment malfunctions or is not reliable, the system will notify the mariner by an alert.

*Functionalities to reduce the workload* are aimed at enabling the user, in a timely and convenient way, to execute all route planning and route monitoring assisted by continuous plotting of the ship's position. Continuous plotting refers to the real-time presentation of information, which should reduce the workload of manually plotting positions using various sources and methods. The user can be aided in route monitoring by the system providing alerts about the information displayed. This is meant to improve their cognitive assessment of the navigational situation, i.e. users will be less busy monitoring the route, because they will automatically, among other things, be alerted about deviation from track, the approach of a wheel over and the danger of grounding. Bridge systems integration is meant to assist the user in monitoring the route progress by integrating the ECDIS with other equipment, e.g. echo sounder, AIS, radar and ARPA functionalities. It is uncertain how system integration is meant to aid route monitoring, but arguably it reduces the user's workload by providing information on a single display, enabling the user to retain an overview of the navigational situation by looking at only one screen.

The IMO standards' notion of what constitutes a contribution to safe navigation can thus be summarised as a reliable chart system offering various functionalities including bridge system integration aimed at reducing navigational workload.

It is up to the manufacturers to resolve how the goals of the system standards are translated into specific design features via international technical standards. (Since the first type approval of ECDIS in 1998, the associated IEC standards have been under constant review and have grown significantly in volume, but further changes seem inevitable.) These features are continuously developed to give the manufacturers a competitive advantage by adding system functionalities and improving user-friendliness in an ongoing design process. This means that the manufacturers are continuously making changes to the systems in the attempt to meet various customer demands, while still effectively meeting the criteria set out in the standards. Where the standards allow little margin for meeting user wants, i.e. optional extras that would be helpful but not essential, manufacturers are also developing 'back of bridge' aids, such as planning stations with extra-large displays that by-pass ECDIS requirements. This design process has resulted in disparities in system features amongst ECDIS makes and models.

2 Res. A.817(19) adopted on 23 November 1995 (Performance standards for electronic chart display and information systems (ECDIS)) and Res. MSC.232(82) adopted on 5 December 2006 (adoption of the revised performance standards for electronic chart display and information systems (ECDIS)).

The development of increasingly advanced system features and the increased integration of bridge systems mean that the ECDIS becomes more than a reliable navigational chart on a screen. It becomes a system that changes navigational practices by enabling the user to access a variety of information to solve other tasks, e.g. executing a turn in real-time or aiding in decisions related to collision avoidance. Arguably, the performance standards did not envisage the extent to which the navigational practices would change as the ECDIS evolved with added functionality and increased bridge system integration.

Before electronic chart systems (ECS) were introduced, paper charts as the primary means of navigation were a commonality of most ships, and paper-based navigation was a core skill for all OOWs. Therefore, the IMO performance standards use paper charts as a benchmark and reference paper charts when determining the minimum standard of reliability of the ECDIS.

Consequently, the IMO performance standards do not explicitly refer to the ECDIS user and the user's navigational context. Because the ECDIS is not meant to change the OOW's core skills and fundamental navigational practices, e.g. when stating that the system *"… should enable a mariner to execute in a convenient and timely manner all route planning, route monitoring and positioning currently performed on paper charts …"* The assumption underpinning the performance standards is that the ECDIS provides a reliable chart on a screen with the added benefit that the manual workload is diminished by automating the manual paper chart work.

> *"ECDIS manufacturer: From the outset, the design criteria for ECDIS was that the user should be able to do exactly what was done using paper charts.*

As mentioned in the introduction, findings from casualty investigations suggested that there was a mismatch between the way ECDIS was used and the way regulators and the system manufacturers expected it to be used as a contributor to safe navigation. A discrepancy which may, in part, have been caused by the continuous development of the ECDIS as more than a paper chart on a screen. This suggests there might be a discrepancy between the IMO performance standards' notion of safe navigation and the ECDIS users' view of the same.

This safety study thus focused in part on the users' perspective on how the ECDIS contributes to safe navigation by offering reliability and by decreasing the users' workload.

# RELIABILITY

### IMO PERFORMANCE STANDARDS

1.2 ECDIS with adequate back-up arrangements may be accepted as complying with the up-to-date charts required by regulations V/19 and V/27 of the 1974 SOLAS Convention, as amended.

1.7 ECDIS should have at least the same reliability and availability of presentation as the paper chart published by government authorized hydrographic offices.

*IMO Res. 232(82) adopted 2006*

## USER VIEWS

An ECDIS comprises hardware (personal computer (PC), screen, keyboard, etc.), software (running presentation library, on-screen user interface etc.), hydrographic data on Electronic Navigation Charts (ENC) and various sensor inputs (Global Navigation Satellite System (GNSS), echo sounder, etc.). These system components have different reliability criteria, e.g. the ENCs must contain dependable information comparable to paper charts, the software must be able to reliably present the hydrographic data, and the hardware must be able to function by meeting certain mechanical standards and by having hardware redundancy.

Most of the users interviewed did not explicitly distinguish between the different system components when asked about the reliability of the ECDIS, i.e. there was no explicit distinction between reliability related to hardware, software, ENC data or sensor input.

> “ *C/O, RO-RO passenger ship: Reliability, that's a lot of things. So, there is reliable information and there is technical reliability …*

Among users interviewed, two implicit conceptions of reliability stand out: technical reliability and information reliability. Technical reliability pertains to the reliability of the technological components, i.e. how likely are breakdowns to occur, and information reliability concerns the accuracy of the displayed information, i.e. accuracy of the hydrographic data and GNSS input accuracy.

The majority of users were found to have a view of the ECDIS as being a reliable technical system, despite some reservations regarding computer-based systems and experience of occasional malfunctions where they had to rely on either the redundant ECDIS or navigate by other means, e.g. using radar or by visual bearing using buoys, landmarks, etc., albeit for a short period of time.
Although reports by ship managers indicated there had been occasions where ECDIS functionality has been entirely lost, these appear to have been infrequent. Users seemed to cope with the minor technical and interface issues, which didn't detract from their positivity over the system's reliability and accuracy.

> “ *C/O, container ship: … we rely on ECDIS a lot and I think it is reliable.*

> “ *C/O, car carrier: … we trust the ARPA so why not trust the ECDIS.*

> “ *3/O, general cargo ship: When I have the radar and the ECDIS and I can look out the windows, I have three sources of information to establish where I am and what I see, and I think when I combine the three I have a more reliable picture.*

Technical reliability is basically viewed as the ECDIS’ ability to consistently solve specific tasks in the daily navigational practices, e.g. updating charts, planning routes, transferring data between workstations, etc. The reliability of the ECDIS is brought into question when the system components malfunction, making task solving difficult, e.g. when updating the ENC database fails, because the computer processor is slow or there is a lack of computer storage capacity. These technical malfunctions are often immediately manifested, causing frustration and mistrust of the system.

> “ *2/O, passenger ship: When it’s not working, I think. If there is something wrong with the ECDIS, or there is something I can’t figure out, then suddenly your mind goes circling around this problem, instead of just navigating … Then you think: Oh, who can I call? I need this thing to work.*

When the ECDIS does not function as expected, the user must diagnose the problem as either a technical malfunction or an operator error. This diagnostic process requires the passage planner to be an expert user.

> “ *C/O, passenger ship: Yes, I have sometimes experienced anomalies. But then I investigate it, and it is usually about me not knowing enough about the system.*

Some users were found to be more prone to experiencing technical problems than others. Those responsible for chart updates, loading ENCs and passage planning experienced more malfunctions, because they were the first to meet the limits of the hardware and software. But they were also the users who were more experienced with the system and were called upon to diagnose problems. This could explain why some users generally considered the ECDIS to be technically reliable, while other users were considerably more sceptical.

Most ships did not have onboard planned maintenance of the ECDIS components and did not carry spare parts, e.g. hard drive, ventilation fans, displays, etc. They mainly relied on having expertise from ashore to repair the ECDIS whenever a problem occurred. The trust in the system thereby primarily resulted from having a spare system rather than by maintaining the system in use to a high standard.

Generally, users were positive about the reliability of the information displayed on the ECDIS when monitoring the ship’s position, both in terms of sensor accuracy and the quality of the hydrographic data. When questioned about ECDIS reliability, the majority of users referred to the Global Positioning System (GPS) as the primary potential source of inaccuracy, which necessitated position verification by the use of line of position (LOP) or by visual observation of e.g. buoys or landmarks. Once the accuracy has been established, the users tend to put trust in the system, e.g. when navigating in confined waters or in port areas.

> “ *Master, passenger ship: … if we are talking position accuracy, I find it very reliable, and I actually use it for my harbour-manoeuvring, so I find it very reliable.*

> “ *C/O, container ship: To maximise the reliability of the ECDIS it is important to challenge the data by all available means.*

It was noticeable that few users referred to the underlying hydrographic data as a potential source of inaccuracy. Few users understood the different zones of confidence (CATZOC) and why these categories could affect the planning and monitoring of the passage. During observations it was not seen that users interrogated the chart for information about accuracy. It could be that the ENCs they were navigating with presented accurate hydrographic data because the waters were well surveyed, or the users were familiar with the area and followed well established safe tracks and therefore did not notice that the hydrographic data was inaccurate. The exception was users on ships navigating in Greenland waters, which are known to be poorly surveyed. In those areas the users did not rely on the ECDIS and consequently mainly navigated using the radar and parallel indices. The subject of the users' trust in ENCs and the underlying hydrographic data will be further elaborated in the next chapter: Emerging Challenges.

## DISCUSSION

When looking to the users' views on the reliability of ECDIS, it was found that overall they had a positive outlook across different types of ships and trades. The majority of users found the various chart systems to be technically reliable, and they had confidence in the quality and accuracy of the information displayed.

Users tended to view the ECDIS as one system and not an information platform consisting of various sources of information with different criteria for reliability. Therefore, some did not systematically distinguish between quality of hydrographic data versus sensor input accuracy, e.g. when assessing the accuracy of the ship's position displayed on the ECDIS. Arguably, ENCs may give the impression that the displayed hydrographic data is more reliable than paper charts. Therefore, the users focus on verifying the reliability of the GNSS sensor input (which will set off an alarm if in error), rather than the accuracy of the ENC.

> "The modernity of ECDIS obscures the fact that the system may be reliant on ENCs with a very low level of reliability."
>
> *Digital navigation: Old skills in new technology – Lessons from the Grounding of the Nova Cura, DSB, 2017*

Two opposing views exist about the reliability of the information provided by the ECDIS. On the one hand, users experienced that the ECDIS consistently provides reliable information, e.g. accuracy of the plotted position. On the other, they are trained to distrust the ECDIS and continuously verify the ship's position by alternative means to the GNSS input, due to unforeseen discrepancies to which the system will not alert the user. Such distrust, which is traditionally expected of OOWs, is challenged, because such discrepancies are rarely encountered.

The majority of users did not necessarily consider the individual sources of information when evaluating the reliability of the information provided by the ECDIS. The reliability of information is thus evaluated by assessing how the system as a whole performs in a specific navigational situation. Given that the various sources of information are usually accurate, and the system rarely malfunctions, the user tends to trust the ECDIS, in terms of accuracy of the information provided by sensor input, hydrographic data and the reliability of the technical components.

So, although the ECDIS is generally considered to be reliable, the practical reality of training and working routines nonetheless often involves doubting the system and alarms, thus detracting from the overall contribution to safe navigation.

# WORKLOAD

### IMO PERFORMANCE STANDARDS

1.5 ECDIS should reduce the navigational workload compared to using the paper chart. It should enable the mariner to execute in a convenient and timely manner all route planning, route monitoring and positioning currently performed on paper charts. It should be capable of continuously plotting the ship's position.

*IMO Res. 232(82) adopted 2006*

## USER VIEWS

The IMO performance standards point to four ECDIS functionalities which are aimed at reducing the workload: The automation of chart updates, route planning, real-time positioning and route monitoring.

Users who had experience from ships carrying paper charts pointed to the automated update of charts as a positive because the manual workload had been significantly reduced. However, the reduction in the workload was not characterised as a contributor to safety per se, presumably because the updates were mainly performed while the ship was in open water with little traffic or when the navigational officer was not performing watchkeeping duties. Users who had never used paper charts typically referred to anecdotal information about the added benefit of automated updates. None of the users referred to increased accuracy in chart updates as an advantage of automated updates.

> *2/O, passenger ship: ... you do not have to manually update the ECDIS like you have to with the paper charts – with glue, and all the stuff.*

> *2/O, passenger ship: I can easily see when it's been updated last, and if I suddenly go into a new area I can quickly, within a few minutes, get an update and install it on the PC.*

When asked about the benefits of ECDIS route planning functionalities there was no specific reference made to how the route planning functionalities contributed to safe navigation. The users focused on how the various route planning functionalities made certain work tasks easier compared to working with paper charts, e.g. loading new routes, making a list of waypoints, plotting waypoints and courses, etc. Distinctively few users pointed to the ECDIS route check as a contributor to safety or reduction of workload.

> *C/O, ferry: We have one-hour port stay, then you just click deactivate the previous route and activate the next route and then you're ready to go.*

> *2/O, RO-RO cargo ship: It saves a lot of time. For example, when you have to change route when we are sailing.*

> *C/O, container ship: … when you have to make new routes, this is much faster than if you should do it in paper charts, of course you have all the waypoints and you can print a waypoint, and make a print with all the waypoint positions, instead of you have to make all this manually.*

> *2/O, passenger ship: If you do not work a lot with the ECDIS then it is faster to make the route in the paper charts if they are corrected. However, calculating distances is slower, but plotting the courses is quicker.*

Continuous automated plotting refers to the real-time positioning of the ship on the ECDIS by a GNSS sensor input. The majority of users found this functionality to be the most beneficial system functionality of the ECDIS because time is saved by not having to manually plot the ship's position on the chart using information from e.g. the GPS and/or radar.

> *C/O, RO-RO passenger ship: … in position monitoring you have more focus on looking out of the windows and monitoring your radar ... I get a quick overview and I have more focus on navigation instead of going back and forth and looking at a paper chart.*

> *C/O, passenger ship: You save time… you become less busy instead of looking at the paper chart you can look out the window and the radar.*

> *2/O, general cargo ship: Close to shore. When you're close to shore it saves time that you don't have to run back and forth plotting the ship's position manually.*

> *Deep sea pilot: Now, you know where you are. And you can focus on anti-collision, and you don't have to run around plotting positions all the time, to be sure that you're in the right place …*

Users were not consistent in expressing how the continuous automated plotting was an advantage besides being less labour intensive than manual plotting. Presumably, the time gained is used for improvement of the cognitive assessment of the navigational situation, i.e. more time for route monitoring, keeping lookout, analysing the traffic situation, verifying the position by other means, interacting with the pilot, etc. Thereby, the user can make more informed decisions about collision avoidance, manoeuvring the ship, etc. Having more time to analyse the navigational situation in terms of deconflicting oncoming traffic, collision avoidance and manoeuvring the ship thus becomes the contributor to safe navigation. During the study it was observed that users only sporadically used the ECDIS in open waters with little traffic indicating that the advantages of having this real-time mental model of the navigational situation was found to be more prevalent in busy and/or confined waters. This observation coincides with the findings from research on how frequently seafarers utilise functions and information available on an integrated navigation system (INS) to perform navigation duties.In open sea the advantage of continuous plotting was found to be minimal, because navigational dangers are few and far between.

"The study showed that during route monitoring the most used system features were display of own ship's position and XTD."

*Vu, Lützhöft and Emad, Frequency of use – the First Step Toward Human-Centred Interfaces for Marine Navigation Systems, The Journal of Navigation, 2019*

The users found the INS to contribute to safe navigation by providing the means to verify the ship's position and for collision avoidance. Instant position verification was obtained by using radar/ENC overlays to assess GNSS accuracy and hydrographic quality, AIS sensor input was used for long-range traffic deconfliction, and the traffic situation was observed and mitigated in conjunction with navigational decisions. ECDIS is thus viewed as a system which assists the OOW in a multitude of tasks, e.g. establishing the position of the ship, collision avoidance, manoeuvring, providing information about weather, etc. This view of the ECDIS is concordant with the IMO performance standards' intentions for INS, namely that INS may assist route monitoring by providing the user with information on a single display, enabling the retention of an overview of the navigational situation, and reducing cognitive workload.

## DISCUSSION

It was found that the majority of users across different types of ships and trades, have an overall positive opinion about the ECDIS' contribution to the reduction of workload. However, ECDIS users are not a homogenous group of professionals, therefore a significant variation was found among the user responses to the various workload topics.

ECDIS users have developed different navigational practices depending on various factors, e.g. type of ship and the trading area the ship is operating in. On a passenger ship operating in regular domestic service, the planners will not use ECDIS route planning functionalities as regularly as on an oil tanker in tramp service. An OOW on a general cargo ship in arctic waters primarily relies on radar navigation, whereas an OOW on a cruise ship in the Mediterranean predominantly relies on the ECDIS for real-time navigation and route monitoring. Additionally, there was a significant disparity between users who had witnessed the transition from paper chart to ECDIS and users who had only used ECDIS.

> "… the survey shows that the use of navigation systems is situation dependent, and the mariners require different sets of functions and data for different scenarios …"
>
> *Vu, Lützhöft and Emad, Frequency of use – the First Step Toward Human-Centred Interfaces for Marine Navigation Systems, The Journal of Navigation, 2019*

The users were found to have a varying depth of knowledge and experience in the use of ECDIS depending on the training and familiarisation they had received, affecting their view on the system's ability to reduce the navigational workload. Some users have little knowledge about the system functionalities and view the ECDIS as a paper chart on a screen and only use the basic functions of the ECDIS. Those users who had misconceptions about how the ECDIS is designed to be used tended to underestimate the workload required when e.g. planning a route or updating charts with Temporary and Preliminary (T&P) notices corrections. Others who were more proficient in the use of ECDIS rely on the ECDIS to provide them with all essential information and use many of the system functionalities. These differences among the users shaped their perception about how much work was required when using the ECDIS.

The ECDIS functionalities were perceived to reduce the manual labour of updating charts, plotting waypoints, etc., but these functionalities were not necessarily viewed as contributing to safe navigation per se. Noticeably, the users who had experience working with paper charts specifically pointed to the reduction of workload of manually plotting the ship's position as the main advantage of the ECDIS, because it freed up time to focus on other safety critical tasks, e.g. route monitoring and collision avoidance. Thereby, the intention of the IMO performance standards was partly met with regards to continuous plotting of the ship's position.

The user's primary objective during route monitoring is to ensure that the planned route is followed, and the ship does not run into danger en route. Having vectorised charts and continuous plotting of position enables the ECDIS to notify the user about navigational dangers ahead and/or that the ship is not proceeding within the specified parameters, e.g. within the Cross-Track Distance (XTD) setting[3]. Thereby, route monitoring is partly automated, and the user is notified about navigational dangers that might have been overlooked when the route was planned, or when meeting navigational dangers which were part of a chart update made after the route was activated. Few users experienced that they had been warned about relevant immediate navigational dangers while on passage. On the contrary, it was emphasised by the majority of users that alarms and warnings were perceived to add to the workload and cause distraction, because they were found to be too numerous and irrelevant. The automation of route monitoring was thus not uniformly found to reduce the workload, and the intention of the IMO performance standards was not met from the perspective of the users.

The challenges related to alarm management will be further elaborated in the section 'Alerts'. Other route monitoring functions were found to be more useful in terms of reducing the workload. Specifically, functionalities which provide information about the progress of the route, e.g. estimated time of arrival (ETA), distance to next waypoint and wheel-over point, were considered useful for users who had previous experience with paper chart navigation, even though these functionalities are a legacy from the paper chart/GPS navigation where the GPS provided the same information.

Even though the study identified an overall positivity towards the ECDIS, problems across the spectrum of use were identified, suggesting that ECDIS design and use has not yet achieved its full potential. User responses and on-board observations identified that basic ECDIS functionalities designed to assist in route planning and monitoring, which were intended to contribute to safe navigation, have brought about new challenges. These will be further examined in the following chapters.

3 Also referred to as the Cross-Track Limit (XTL), Cross-Track Error (XTE) and Safety Corridor.

# 3 EMERGING CHALLENGES

# INTRODUCTION

It is arguable that ECDIS' contribution to safe navigation could be measured against an increase or decrease in the rates of vessels grounding. However, among other things, the phased carriage requirements for ECDIS over several years, the absence of available data regarding designated primary means of navigation, the obligation for flag States to investigate only 'very serious' marine casualties and the limitations of marine accident databases, currently make such a straightforward quantitative assessment impossible. Nonetheless, the themes emerging from the analysis of 15 investigations into vessel groundings that were conducted under the auspices of the IMO Casualty Investigation Code between 2008 and 2015 (Table 1) suggest that the way the ECDIS was used during route planning and/or route monitoring compromised safety, rather than contributing to it.

The contributing factors identified in these investigation reports included:

- passages being planned over navigational dangers;
- audible alarms being disabled;
- alerts being ignored;
- the lookahead not being set;
- the safety contour and safety depth settings not being appropriate to UKC (under keel clearance) requirements;
- the XTD being wider than the navigable channel;
- the use of ENCs significantly over compilation scale;
- ENC availability and inaccuracy;
- insufficient system knowledge; and
- the absence of oversight and supervision.

Although, on the face of it, the incidence of so-called 'ECDIS-related groundings' seems quite low, the recurring nature of some of the contributing factors identified, suggests that any contribution to safe navigation delivered by ECDIS has been accompanied by problems or difficulties with its use in the various phases of a voyage. The accidents listed in Table 1 occurred during passages in confined, coastal and ocean waters with commensurate levels of bridge manning.

For convenience, the contributing factors identified through investigation have been categorised in Table 1 under ENC reliability and presentation, route planning and execution, route monitoring, system interfaces and system knowledge. The categorisation is indicative rather than definitive, and a degree of overlap is unavoidable and acknowledged. It is also acknowledged that the accident reports reflect investigations of varying depths and differing analyses such that the contributing factors identified might not have actually 'contributed' to an accident and that other, less obvious factors that were contributory, were potentially overlooked. However, factors similar to those shown in Table 1 were also identified by several company investigations of other groundings, which were shared in confidence by shipowners with MAIB/DMAIB through industry working groups and committees, and generally supported the 'official' data. The company investigations also identified additional factors such as routes planned on paper charts being incorrectly input to the ECDIS and vessel position not being verified by alternate means.

The link between accident causation and safety settings (safety contour, depth and XTD) and display settings (scale/overscale) frequently made in accident investigation reports aligns with the emphasis of 'proper management' of the ECDIS in official texts. However, it has also tended to polarise attention on user competency. Difficulties associated with user interaction and experience, although acknowledged to some degree in some of the investigation reports, industry journal articles and anecdotal stories from users, have been given a significantly lower profile.

> "Despite the focus on the causal contribution from the interplay between the ECDIS and the planner, the conclusions in the official accident investigation reports are predominantly directed towards the abilities of the ECDIS operator to use the equipment properly, and to a lesser extent on the features of the ECDIS. The reports do not at all investigate how the equipment could have helped planners, by offering better support in reaching their contextual goals."
>
> *How a ship's bridge knows its position – ECDIS assisted accidents from a contemporary human factors perspective, Mads Ragnvald Nielsen, Lund University 2016*

The following sections on ENCs, route planning and route monitoring explore the use and usability of ECDIS from the user perspective against expected navigational practices. The final section highlights user difficulties and wants connected with how they interface with ECDIS, and how ECDIS design influences how the system is utilised. User difficulties are discussed in relation to their origins, improvements that have been implemented or are in progress, and problems that are yet to be resolved.

# ENCS

## USER VIEWS

***Availability and Accuracy***

ENC accuracy was raised infrequently by users when questioned about ECDIS reliability, with some responses reflecting a general confidence in the provenance of 'official' charts and a lack of awareness of the implications of survey quality and prevailing regional variations. None of the users spoke of experiences related to the use of ENCs with undefined datums, in which the differences with WGS 84 datum can be considerable, and which contributed to the grounding of *Kea Trader* (Table 1).

> *2/O, container ship: The charted data is reliable. I have never had something that was not correct.*

> *3/O, ferry: … of course, chart data must be reliable, it comes from the hydrographic office.*

Users commenting on potential ENC inaccuracies were a minority and were mainly those who had experienced issues concerning tangible features such as navigational aids and port infrastructure. These users were also cognizant of regional differences with some having experience using a mix of paper, raster and unofficial charts due to the unavailability of ENCs in some geographical locations. They also generally saw little value in the mandatory carriage of paper charts where ENCs were not available, citing the advantages of real-time positioning on raster charts as a preferred alternative means of navigation.

> *“3/O, cruise ship: In Madeira there is still no update on the chart for the new berth, it’s been there for over a year now.*

There was an awareness of the CATZOC system (Figure 3), but ECDIS users on fixed or familiar routes, or operating within limited geographical areas and using the same ENCs, had little reason to research ENC data quality (Figure 4). Where CATZOCs were used, it was generally only when planning, and while ’six stars’ provided a degree of comfort, the ‘two star’ and ’U’ categories only informed users of uncertainty. Some users also misconstrued the ’U’ to mean ‘un-surveyed’, and none seemed to be aware that the CATZOCs applied only to the bathymetry (depths, contours, sub-merged rocks and reefs, etc.), not to features such as buoys, jetties and Traffic Separation Schemes (TSS).

# Zones of Confidence (ZOC) Table

Cartographers use Category Zone of Confidence (CATZOC) values to highlight the accuracy of data presented on charts. The following table outlines the position accuracy, depth accuracy and seafloor coverage for each ZOC value to help you manage the level of risk when navigating in a particular geographic area. The information and values used in this table has been taken from the IHO’s ‘Regulations of the IHO for International Charts and chart specifications of the IHO’ white paper.

| ZOC [1] | Position Accuracy [2] | Depth Accuracy [3] | Seafloor Coverage | Typical Survey Characteristics [5] |
|---|---|---|---|---|
| A1 | ± 5 m + 5% depth | =0.50 + 1%d<br>Depth (m) / Accuracy (m)<br>10 / ± 0.6<br>30 / ± 0.8<br>100 / ± 1.5<br>1000 / ± 10.5 | Full area search undertaken. Significant seafloor features detected [4] and depths measured. | Controlled, systematic survey [6] high position and depth accuracy achieved using DGPS or a minimum three high quality lines of position (LOP) and a multibeam, channel or mechanical sweep system. |
| A2 | ± 20 m | = 1.00 + 2%d<br>Depth (m) / Accuracy (m)<br>10 / ± 1.2<br>30 / ± 1.6<br>100 / ± 3.0<br>1000 / ± 21.0 | Full area search undertaken. Significant seafloor features detected [4] and depths measured. | Controlled, systematic survey [6] achieving position and depth accuracy less than ZOC A1 and using a modern survey echosounder [7] and a sonar or mechanical sweep system. |
| B | ± 50 m | = 1.00 + 2%d<br>Depth (m) / Accuracy (m)<br>10 / ± 1.2<br>30 / ± 1.6<br>100 / ± 3.0<br>1000 / ± 21.0 | Full area search not achieved; uncharted features, hazardous to surface navigation are not expected but may exist. | Controlled, systematic survey achieving similar depth but lesser position accuracies than ZOC A2, using a modern survey echosounder [5], but no sonar or mechanical sweep system. |
| C | ± 500 m | = 2.00 + 5%d<br>Depth (m) / Accuracy (m)<br>10 / ± 2.5<br>30 / ± 3.5<br>100 / ± 7.0<br>1000 / ± 52.0 | Full area search not achieved, depth anomalies may be expected. | Low accuracy survey or data collected on an opportunity basis such as soundings on passage. |
| D | *Worse than ZOC C* | Worse than ZOC C | Full search not achieved, large depth anomalies expected. | Poor quality data or data that cannot be quality assessed due to lack of information. |
| U | Unassessed - The quality of the bathymetric data has yet to be assessed | | | |

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*Figure 3: CATZOC Table*

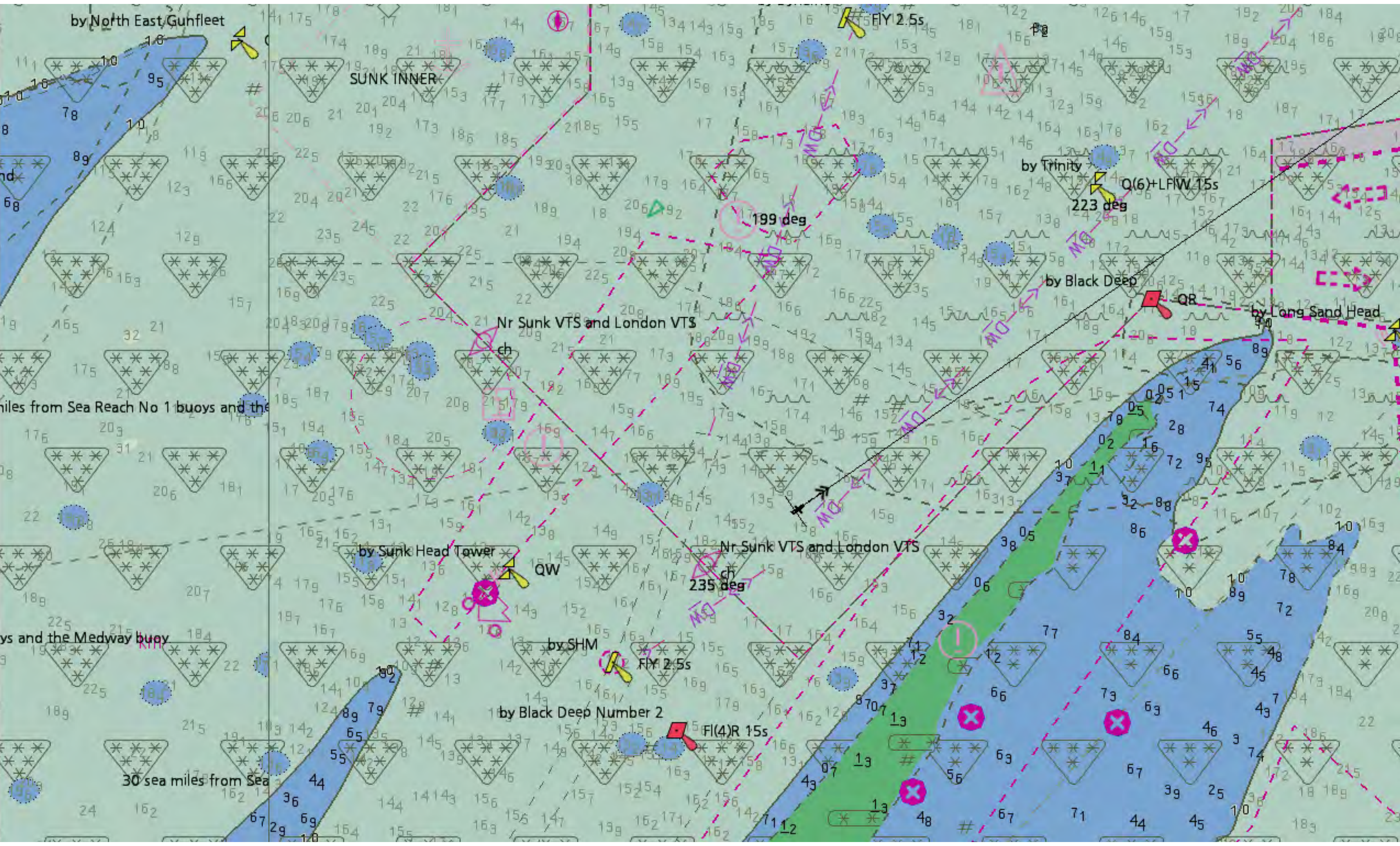


*Figure 4: CATZOC as displayed by ECDIS*

> *3/O, bulk carrier: We can also check by using the CATZOC, we can say they are perfect as they have six stars.*

> *Master, product tanker: … we went to West Africa and these were all grade U, so you should not rely on these chartered depths, they are +/-200 m so I cannot use them for my calculation for UKC.*

> *C/O, cruise ship: when we sailed in the US and we checked the accuracy of the charts, they do not give you the accuracy even if they are well surveyed, but they identify as not giving you reliable data - when you make voyage planning these charts show as un-surveyed*

The vertical error values provided by CATZOCs were included by some planners in UKC calculations, in compliance with Safety Management Systems (SMS) or prompted by inspection observations.

> "Allowance for CATZOCs was not taken into account/applied while calculating UKC for the last passage plan."
>
> *Vessel Inspection Questionnaire (VIQ) observation, 2018*

> *2/O, car carrier: We also have to apply a correction depending on the CATZOC, I have a table for this and I have to note it down on the passage plan, this is on the checklist. When you are doing your UKC calculations you have to take this into consideration.*

Some users seemed comfortable with this practice, but it caused difficulty for others when it prevented minimum UKC requirements from being met. In such cases, it was mostly left to the ships' planners and masters to decide whether to proceed based on factors such as previous visits, sailing directions, advice from pilots and other sources of information, as well as varying degrees of commercial pressure.

### *Data Granularity and Fidelity*

Comments from officers responsible for voyage planning reflected a frustration at the ECDIS frequently defaulting to a safety contour that did not separate safe from unsafe water due to insufficient contour density.

> *C/O, cruise ship: I am always working outside of what it defines as the safe waters, especially in tidal ports, this could be more reliable. I would like to be able to set it. You adjust the system, so it looks as if you can enter the port.*

> *C/O, oil/chemical tanker: We need more contours, so we can fit in all kinds of drafts for all sizes of ships.*

> *2/O, LNG tanker: For turning in Milford Haven the minimum depth was set at 11 m, you cannot keep 15 m contour everything will be blue, but I cannot go to 11, so I need to go in and pick the 10 m contour and then add a manual correction to make my safety contour 11 m. Our rules are simple, we are not allowed to cross over the blue, so we do everything that we can do to avoid it.*

Irritation was also observed among users at the number of alerts generated by isolated danger symbols[4] (the 'screw head') (Figure 5) during planning (automatic route check) and monitoring (look-ahead) which had to be queried using the 'hover' or 'pick report' function to determine whether danger actually existed.

In many cases, the seabed obstructions triggering the indications had no bearing on a vessel's safe navigation as alerts were often generated when a vessel was in deep water, because the depth of water over an underwater feature (rock, wreck or other obstruction) was unknown. Indications were also generated by seabed features such as foul ground, which were not a concern unless anchoring.

> *C/O, cruise ship: Everything that on paper charts was surrounded by dots, like dangers, will pick up. Even this one like foul ground or something it will pick up everything.*

During the onboard observations, it was seen that transition from one ENC cell to another was not always seamless, with differences in the detail of features such as depth contours and soundings a regular occurrence. Although this did not appear to create specific problems, it was disconcerting for some users.

> *Master, cruise ship: That cell changes there but nothing matches up, that's what I hate. The edging and things don't match. I mean why is it like that.*

4 The Isolated Danger Symbol is displayed, if any underwater feature like wrecks, rocks or other obstructions has a depth less than the [selected] safety contour in waters beyond the safety contour.

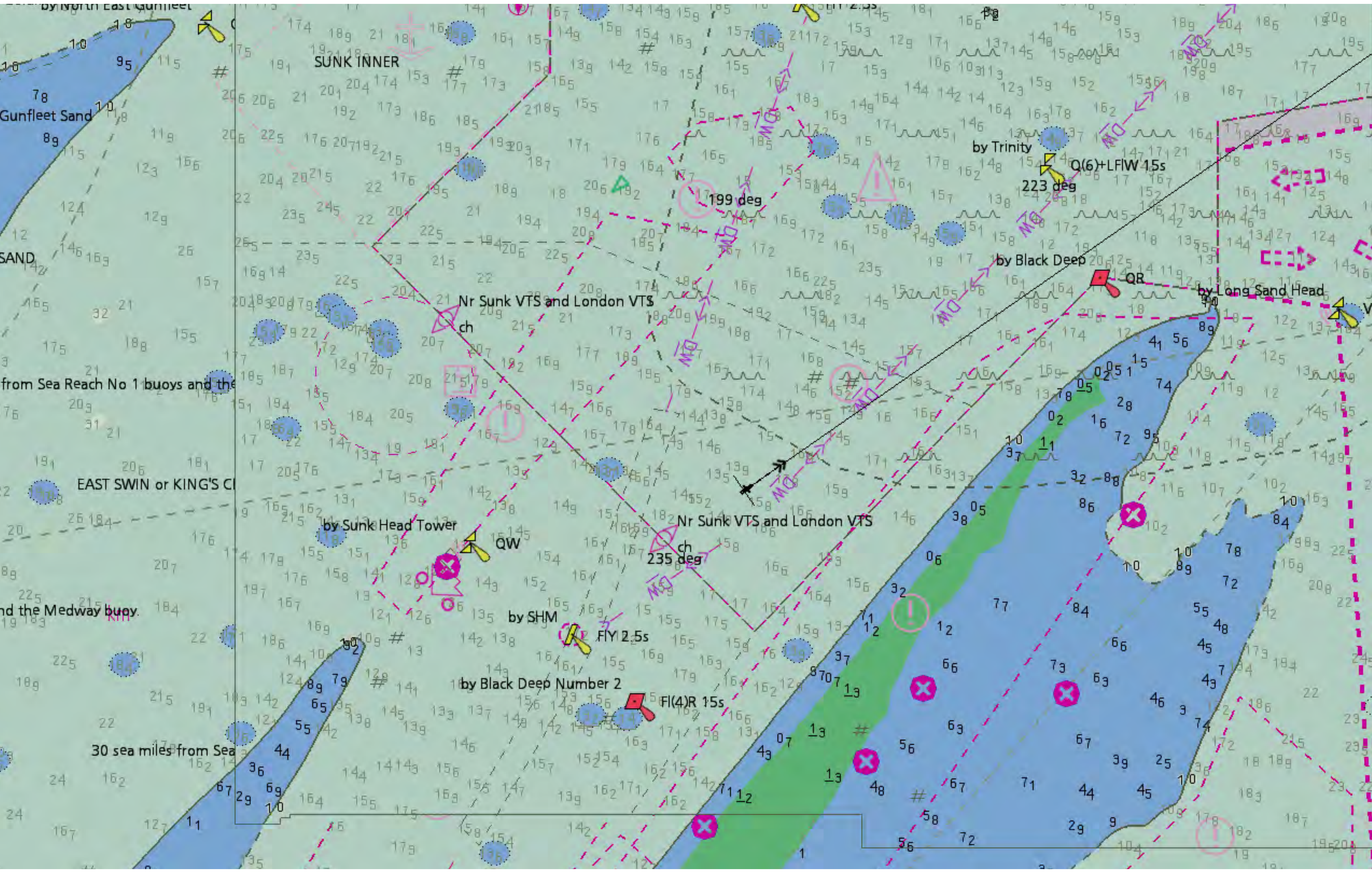


*Figure 5: Isolated Danger Symbol*

### *Supply and Update*

Users and ship managers expressed that the supply of ENCs was more efficient than the supply of paper charts. Although some relatively minor difficulties were encountered, ENC holdings could be tailored to ships' trading patterns with permits allowing access being forwarded to ships without delay. For tramping ships, schemes such as 'Pay As You Sail' allowed freedom of planning and reduced both cost and effort in ensuring vessels had the required hydrographic information on board. Ship managers operating vessels on fixed routes or limited localities reported little change in cost.

Methods of updating ENCs varied between distributors and ECDIS model and installation, e.g. getting updates from ashore on Compact Disc (CD) or Universal Serial Bus (USB) or downloading files via an internet connection and transferring the updates to the ECDIS via USB. User comments overwhelmingly indicated that the speed and accuracy of the automatic ENC updates was a vast improvement on manual paper chart updates. The time saved was viewed as the most significant benefit by far, with the only major drawbacks cited concerning technical problems including internet connectivity and large file sizes.

> *2/O, RO-RO passenger ship: … sometimes our connection is so bad, so it can be difficult to have the file loaded to our computer. But I think we have figured out how to avoid this; if we get the file in the port where the internet is good, then this is not a problem, but in the North Sea it would take hours to download it.*

> *2/O, passenger ship: … whenever the downloaded update files they fail, we have to do it again, sometimes three times maybe, and it takes a lot of time to extract these files. And also, we have an internal policy about when we update, and we only do that in port on weekdays, and we don't do it after midday, because if something goes wrong, it's not likely anyone would be able to help us. So, that limits the time where you're able to do it and that means that you have to attempt to do it several times in a week.*

Some users experienced in paper chart practices expressed concern that the knowledge previously acquired in the process of manual correction, such as the relevance of updates and understanding of symbology was now lost – a view corroborated to some extent during the study, when many users were seen to rely on 'hover' or 'pick reports' when responding to questions regarding display symbology.

> *Master, cruise ship: People just put the disc in and that's my concern. Updates just happen whereas before, you would read everything, and you would manually re-write it, and that's what I prefer, but that's me being a traditionalist.*

Other problems were mainly related to the voyage planners not understanding how the system was intended to be used or how to do fault finding if it did not perform as expected or even malfunctioned.

> *C/O, passenger ship: … we had a problem with one of the update CDs which made a wrong update. It actually blocked the system. All of our charts were gone like this, and we could not find out what was wrong, so we had to use a couple of hours and get service.*

> *2/O, passenger ship: After two years onboard, I found out there was a menu called 'update all ECDIS stations', or whatever it is called, and before I had to plug in the USB stick in every single computer; much more time-consuming and annoying than just this one click.*

Planners were found to be nervous about making mistakes which could result in system malfunctions. The concerns about causing system breakdowns were mostly based on previous experiences, which resulted in them doubting their own capability and a distrust in the reliability – in part caused by confusing interfaces.

> *2/O, passenger ship: The system is too complicated – I have to go to the menu TRANSFER when updating the charts.*

The distrust in the system resulted in the implementation of detailed written instructions about how to do updates, purchase new licences, etc. to ensure that the updates were performed correctly. Additionally, some planners did not have sufficient training in making updates and did not fully understand how the update functionality worked. Typically, the planners were trained in updating the system by other users or followed the onboard instructions. If they encountered unique problems, usually their only option was to contact the onshore technicians.

> *2/O, container ship: By accident I deleted the charts after I had installed them, and then I want to download them again, to install; the system did not allow me to do that … So, I had to get in contact with tech support.*

Although the automatic update of ENCs was completed by all users, the application of manual updates required by T&P notices and Navigational and Meteorological Warning Broadcast Service (Navtex) messages was not universal. The Admiralty Information Overlay (AIO) was frequently used to identify the presence of extant T&P notices on the ENCs in use, but many planners were not familiar with manual updates and could not recall being trained in this practice. The course providers consulted during the study verified that they did not address these topics during the generic training courses.

## ENC – DISCUSSION

The data used in ENCs is generally the same data used in paper charts. It is based on the same surveys and other sources and, with some exceptions such as dredged areas, cautions and objects of low accuracy, the display of bathymetric data is generally similar on ENCs to that on paper charts. However, the use of ENCs in ECDIS necessitated the introduction of additional chart and plotter features such as the safety contour and the isolated danger symbol to support ECDIS functionalities. It is evident from the views of users collected during this study that the effectiveness of these features has been diminished by the quality of the underlying data.

The setting of an immediately recognisable boundary between safe and unsafe water, based on a controlling depth that triggers an alarm when a ship is about to cross it, is central to the performance standards, but the 'safety contour' often fails to efficiently deliver in this respect due to insufficient contour density on the ENCs. The frustration derived from ECDIS not separating the safe from the unsafe water, which results in unhelpful alarms in both route checking and route monitoring, significantly undermines the usefulness of the safety contour in many instances. It also undermines the system's credibility overall.

The safety contour generated by ECDIS is based on user input but its definition and presentation are governed by the density of the depth contours on the ENC, which is the same as on paper charts (2m, 5m, 10m, 20m and 30m (equivalents on fathom charts)). Initiatives are being taken by some national HO (e.g. UK and Australia) to improve contour density in busy areas, but progress is slow. However, although increased contour density is limited by insufficient survey data on many ENCs, it is anticipated that more could be done to provide high density bathymetry in areas with an A1 CATZOC, where the vertical error is 0.5m (+/- 1% depth).

Similarly, the isolated danger symbol is used to warn ECDIS users of seabed obstructions lying in the safe water defined by the safety contour, but the lack of bathymetric data frequently reduces the symbol's usefulness where the safety contour displayed does not accurately depict the safe water, and where the depth of water over an obstruction is unknown. In the first case, there is a risk that isolated dangers in the waters inside the safety contour through which it is generally safe to sail will not necessarily display as an isolated danger symbol. In the latter case, ECDIS assumes a zero-depth clearance over the potential hazards and indications are generated where no danger exists, for example diffusers in an area where the water depth is over 50m.

In its investigation into the grounding of *Roebuck Bay* on Henry Reef in the Great Barrier Reef, Queensland Australia (Table 1), the Australian Transport Safety Bureau (ATSB) report also identified the additional risk of using point feature objects (isolated danger symbol) to represent physical features of relatively significant spatial extent on an ENC such as reefs (see also *Kea Trader* – Table 1). Using isolated danger symbols to represent such physical features can mislead mariners regarding their extent and potentially reduce the effectiveness of the ECDIS safety functions. Following the accident, the Australian Hydrographic Office (AHO) re-encoded 2200 underwater obstruction area features on 243 ENCs to create obstruction areas that were the same size as the isolated danger symbol, to ensure the way that the symbol functions electronically corresponds to the way it displays visually. The Seafarers Handbook for Australian Waters (AHP 20) was also revised to address misconceptions among mariners regarding the accuracy of bathymetry within ENCs and its impact on route planning and monitoring.

Unlike inputs to ECDIS such as the gyro, to which type approval regimes and performance and test standards prescribe a level of reliability, the accuracy of ENCs is subject to many variables. Despite this, users are not informed of potential ENC inaccuracies in the same way as they are with GNSS and other sensor inaccuracies. Whereas the loss of a GNSS input triggers an audible alarm and several visual indications in various locations, the cautions provided to warn seafarers of ENCs with undefined datums, where positional inaccuracies can be significant, are much less obvious and require probing. In addition, the visualisation of embedded survey data quality and accuracy through the CATZOCs is not universally helpful.

Discussions with hydrographers indicate that the CATZOC system was introduced to assist the 89 national HOs in categorising bathymetric data with respect to horizontal and vertical accuracy. It was not intended to be used by seafarers to provide an accurate margin of safety by applying the error values in UKC calculations, as now expected by some. The use of the CATZOC error values in UKC calculations leads to difficulties in several areas. These include; undue confidence in the accuracy of the calculation, the calculations differing between ships navigating on ECDIS and those with similar draughts using paper charts with source data diagrams, and safety contours being set that do not correspond with previous experience and local knowledge. It is very difficult for masters to justify their refusal to enter a port on the basis that UKC requirements cannot be met due to the vertical inaccuracies determined by CATZOCs when the conditions are the same as upon previous entries.

In its investigation report into the grounding of Nova Cura, the Dutch Safety Board recommended the IHO to: '*Impose conditions for the age and reliability of the data used to compile ENCs and stimulate the decrease of ENCs with CATZOC U.*' (Dutch Safety Board – 'Digital navigation: old skills in new technology – Lessons from the Grounding of the Nova Cura, 2017).

Before and since then, measures to improve ENC coverage, quality, accuracy and density, and the interaction between ENC data and ECDIS functionality have been ongoing. The introduction of the IHO publication S-52 Presentation Library (Version 4.0) among other things, reduced the number of charted features requiring audible alarm. IHO's recent publications S-65 (ENC production guidance) and S-67 (Mariner's Guide to Accuracy of Depth Information in an ENC) are intended to assist national HOs in producing ENCs with high density contours where sufficiently accurate source data exists and providing more information to seafarers on the application of CATZOCs. New hydrographic standards (S-100, S101 and S102), are also in the pipe-line, and these could potentially include improvements in ECDIS, such as real-time water levels and in-built system checks of positional, vertical and horizontal errors, as proposed by the AHO to IHO's Data Quality Working Group.

> "… some (rather remote) areas are not fully covered with ENCs in appropriate scales; there are still problems with geographic overlapping and the quality of the underlying survey data needs improvement in many areas. … What appears to be the predominant need from the users is for dense bathymetry and real-time application of tide water level."
>
> *Mathias Jonas, IHO Secretary-General, Hydro International 'The Shape of the Future' May 2018*

Although differences in survey coverage and quality are likely to persist between geographical regions for reasons of resource, achievable goals for improving the utility of ENCs could include the provision of high density charts for areas in which the standard of survey data already exists, determining the water depth above underwater obstruction where it is currently charted as unknown, the elimination of ENCs with undefined datums and including all temporary information, which is currently provided with respect to paper charts through T&P notices, in the ENC updates.

As a lack of ENC coverage in some remote regions is likely to continue into the foreseeable future, the requirement for paper charts to be carried where this arises, warrants review. User feedback indicates that such a practice adds no value, with real time positioning on a raster chart being the preferred workaround.

The diminished effectiveness of chart features due to the lack of quality of the underlying data, the CATZOC system not being intended to be used by seafarers to provide an accurate margin of safety, and ECDIS not separating the safe from the unsafe water are in combination detrimental to the general credibility of the system, thus not contributing directly to safe navigation. Solutions include working to improve ENC coverage, quality, accuracy and density and national HOs adopting common strategies for survey coverage and quality.

# ROUTE PLANNING

## USER VIEWS AND ONBOARD OBSERVATIONS

*General Practice*

During the study, officers responsible for voyage planning were asked to describe how plans were created in ECDIS and how they were checked. Voyage planning was usually undertaken by one planner, typically but not exclusively, a 2/O. On board cruise ships, the planner responsible for voyage planning was a 1/0-C/O, with other officers assisting with specific aspects such as chart ordering and maintenance and checking UKCs.

Most routes on board the ships visited were found to be the product of ‘cutting and pasting’ and adjustments to previous routes, with only a few planners having to plan new passages. Planners experienced with paper charts were able to compare passage planning on ECDIS with that on paper charts, citing the setting of safety parameters to manage alerts and display configuration among the new tasks ECDIS had brought. In addition, they expressed difficulties in planning on a small screen but identified the ease and speed of using waypoints to generate or amend a route among the significant advantages.

> “ *2/O, container ship: Passage planning in the old days was much harder because you had to take a general chart and then transfer onto the smaller charts, now on ECDIS you pick the chart you need and then you can zoom in and organise.*

> “ *2/O, service ship: Sometimes, I find the easiest way to do it is if you have a start and finish point and then you can sort of put intermediate waypoints in, you can drag it away from certain dangers, things like that, just using the VRM to check the distance off. I start with a straight line, it’s much easier that way.*

Many planners acknowledged that a lot of information was embedded in an ENC and needed to be extracted. They also expressed that the use of information from publications such as Sailing Directions and Ocean Passages for the World remained usual practice during planning. However, the use of such publications was not observed during the ship visits, and one planner was open in stating that the research of publications was often omitted.

> “ *3/O, cruise ship: On ECDIS you wouldn’t tend to get the publications out, you would tend to jump straight in there and do the planning and maybe pass the appraisal system which you generally wouldn’t do on a paper system.*

Some users expressed annoyance at the difficulty experienced when trying to apply system tools and features such as parallel indices and text notes in ECDIS. However, this was not universal and was usually related to system functionality and interfaces such as menus, the use of keyboards, and font size and colour.

> “ *2/O, LNG tanker: On the paper chart you can quickly write down a note in pencil on the chart, you cannot do that on an ECDIS. On a chart you might want to mark ‘call master’, you just write on the chart, but here you have to go into a menu and type the note and then put the note on the layer …*

> “ *2/O, service ship: I find setting up parallel indices more awkward on the ECDIS than on a paper chart. If you are trying to pre-set them before your voyage, measuring them out with VRMs, it just doesn’t really work. You are almost better off doing them on passage, but that kind of defeats the object.*

Observations indicated that other traditional tools such as lead marks and wheel-over bearings were seldom planned when using ECDIS. The calculation and plotting of wheel-over positions was also variable with some using speed, turn radii and rate of turn as the driving factors, and others content to set a prescribed distance from each waypoint or rely on navigation by eye (either by looking out of the window or at the ECDIS) and to not mark the wheel-over positions at all. Some planners, mainly those on board vessels equipped with track control systems, expressed difficulty in relation to wheel-overs when planning for specific navigational situations, such as manoeuvring in port areas and transiting narrow channels with long turns that required the manipulation of vessel speed, turn radii or the insertion of additional waypoints to make the plan viable within the system.

> “ *2/O, container ship: When planning routes a few times, in port sometimes with a big turn radius, it was really impossible to adjust, when you are coming from the berth and there are a few waypoints … you must make amendments in the passage plan, say you could not make the turn, you have to make it kind of false radius, its manoeuvring, it would be easier if these waypoints could have different limits in port, I had to make some waypoints, even what I did, decrease speed or increase radius I could lose plenty time and eventually had to do some false waypoint that we would not even go to.*

> “ *2/O, container ship: If you have two waypoints that are near each other and you have some crazy speeds set up or too small speed or the radius is too small it will not give you the opportunity to activate the route, it will tell you that you cannot make this turn, do something with the radius of the speed, so it would let you activate the route.*

> *C/O, cruise ship: ... so I draw the track down the middle of the turn into the middle of the Thorne channel, so I'll just put a waypoint, so you have three waypoints so the actual waypoints are actually linear, that will give me a curve, I'll set a 1 mile and I see its too shallow and we cross the bank so I put on half mile and it will curl like that but we might not be in the middle of the Thorne channel so I drag the waypoint and put it where ever it needs to be to get the track in the middle of the Thorne channel and in safe water, it doesn't matter where waypoint is, you are never going to reach it.*

***Defining Safe Water***

As mentioned previously, many planners found that the safety contour frequently did not define the safe from the unsafe water. This resulted in routes being planned that passed over the safety contour and through the 'unsafe' water as displayed on the ECDIS (Figure 6). However, planners did not always highlight the water that was unnavigable by the insertion of user-defined limiting danger lines (Figure 7) or 'no-go' areas. Instead, many masters and planners relied on either the visual representation of the bold depth soundings defined by the 'safety depth', which on some systems meant an indication was triggered by the lookahead (Figure 8), simple text annotations (Figure 9), staying within a buoyed channel (Figure 10), pilots' advice or familiarity with an area.


*Figure 6: Track planned over safety contour*

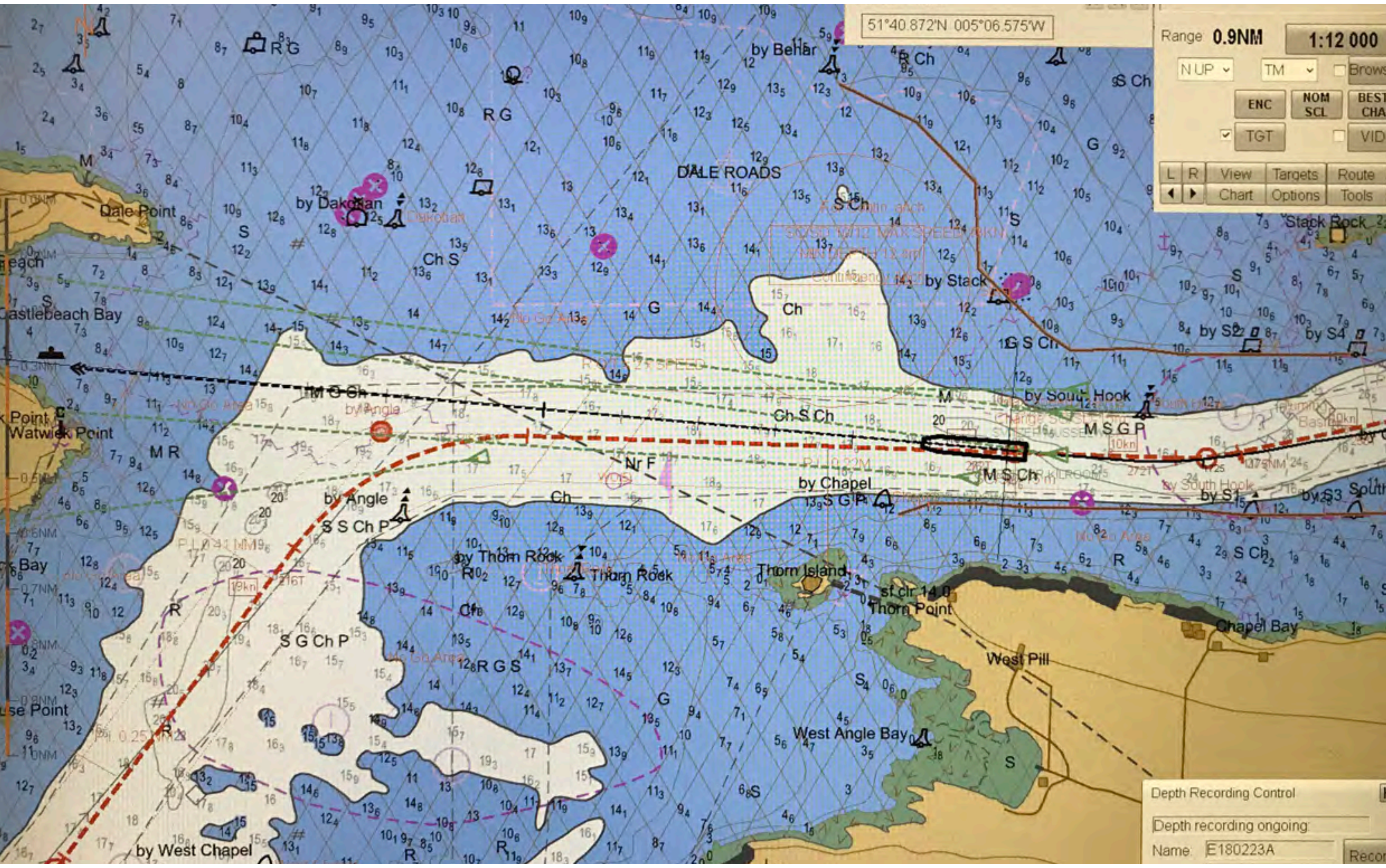


*Figure 7: Absence of danger lines or no-go areas*

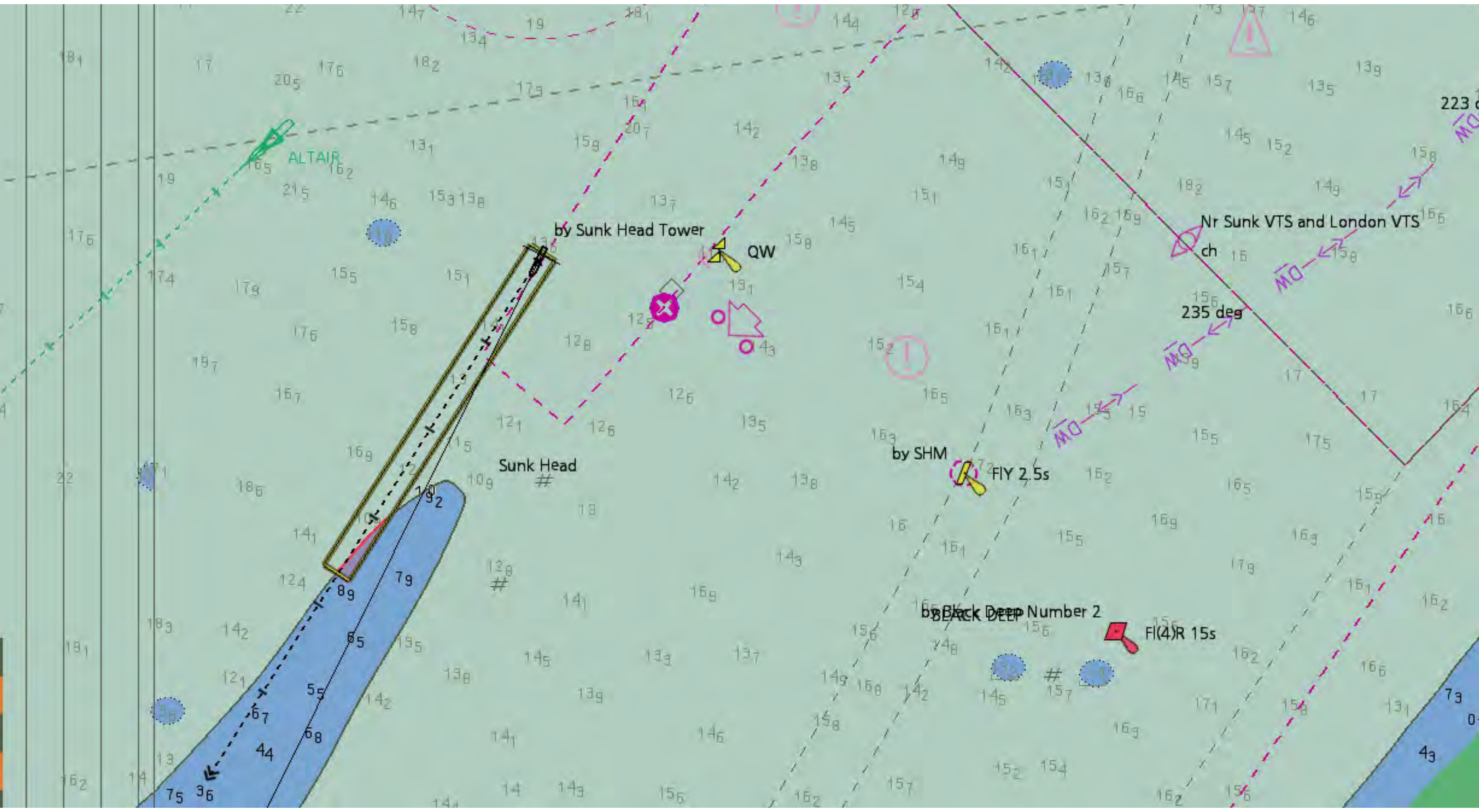


*Figure 8: Indication triggered by the look-ahead*

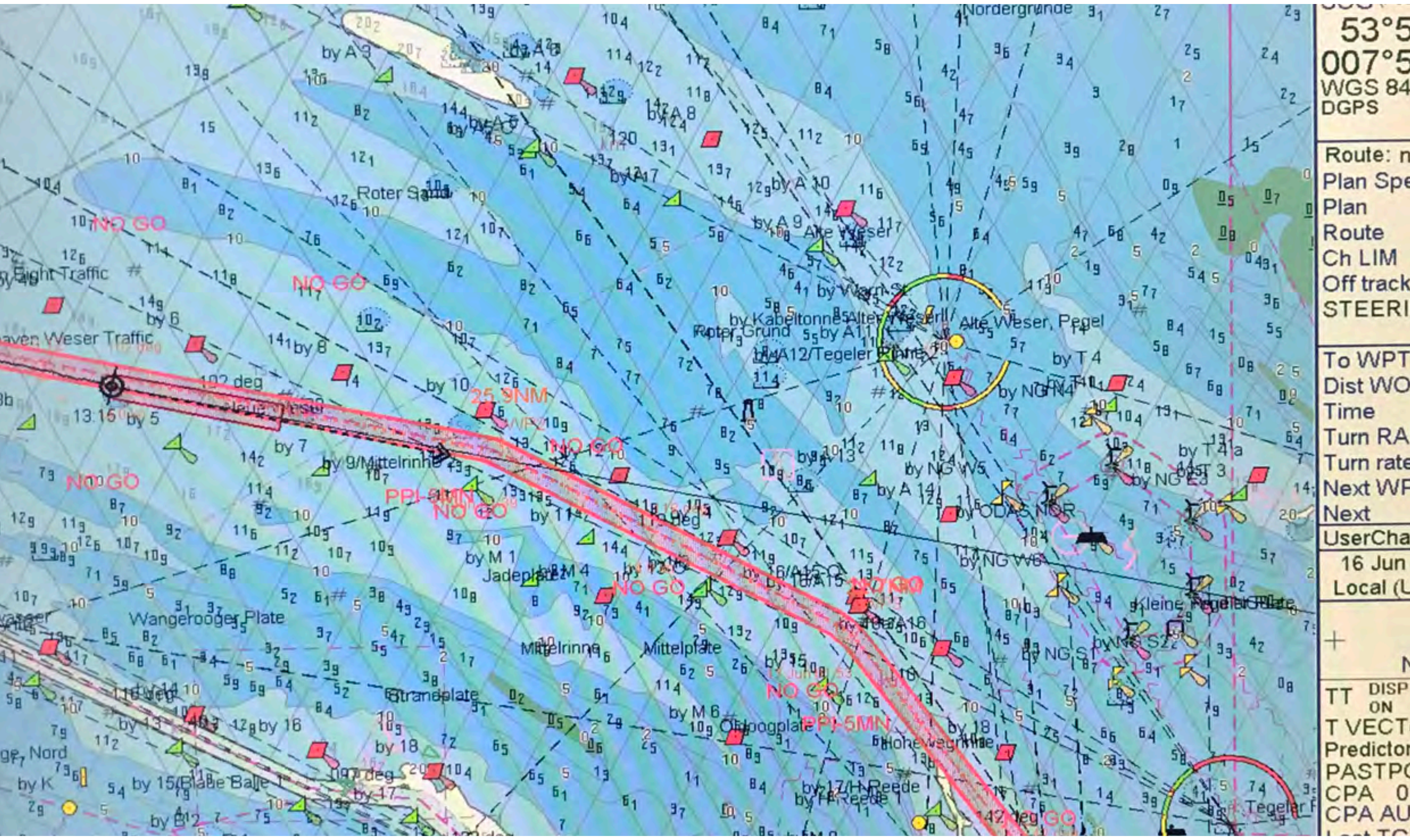


*Figure 9: Simple text annotations*


*Figure 10: Ship within buoyed channel*

The ease of inserting user-defined limiting danger lines that could be used to trigger an alarm in the same way as a safety contour, varied between ECDIS models. While some planners were able to insert user-defined limiting danger lines without difficulty, others could not, and some were unaware of the significance of these features and did not attempt to use them. Some planners also did not know the difference between safety depth and safety contour, or the relevance of the height of tide when calculating these parameters.

> *2/O, car carrier: The safety contour does not consider the tide. As I set my safety contour based on the draft plus UKC plus squat, before arrival Savannah I set my safety contour at 14 m and the master could see that my route was running in 13 m but we checked the timetables and even when passing the 13 m we had a tide of 2 m, so we had 15 m and was safe.*

In many instances the height of tide was not included in the safety contour calculation. Consequently, a 'worst-case' scenario was displayed and the probability of crossing the safety contour was increased.

Masters and planners also adopted varying strategies regarding the planned width of the XTD, ranging from following SMS requirements, which typically detailed specific distances in the differing voyage segments of open water, coastal and pilotage, to applying their own discretion. In the latter case, some masters and planners preferred the XTD to be as narrow as 30m, while others adjusted the widths on both sides, but some did not use the XTD at all in open water (Figure 11) or in pilotage waters (Figure 12).

> *3/O, service ship: The width of the safety corridor is stipulated by the captain. I would prefer to have much wider safety corridors.*

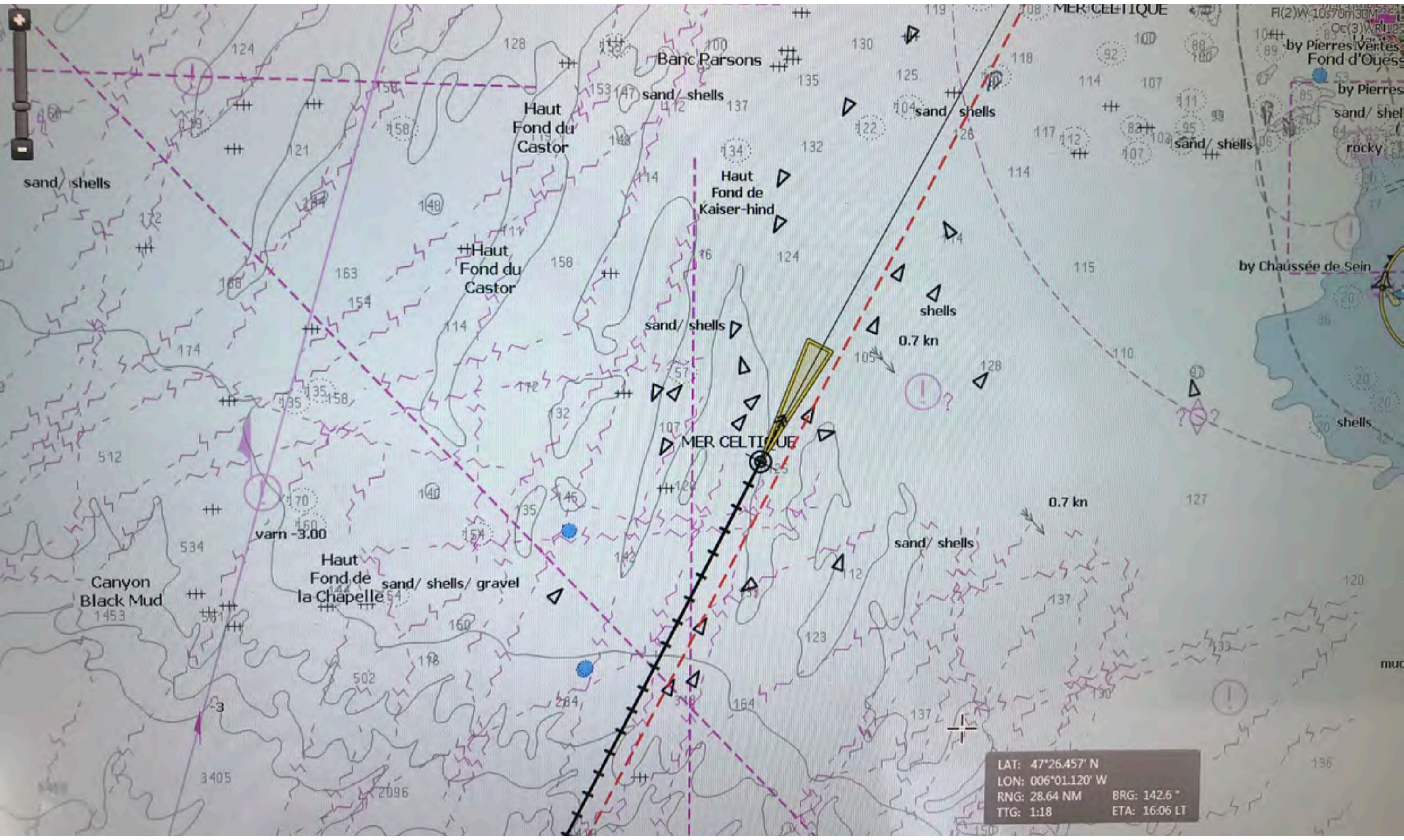


*Figure 11: Track without XTD*

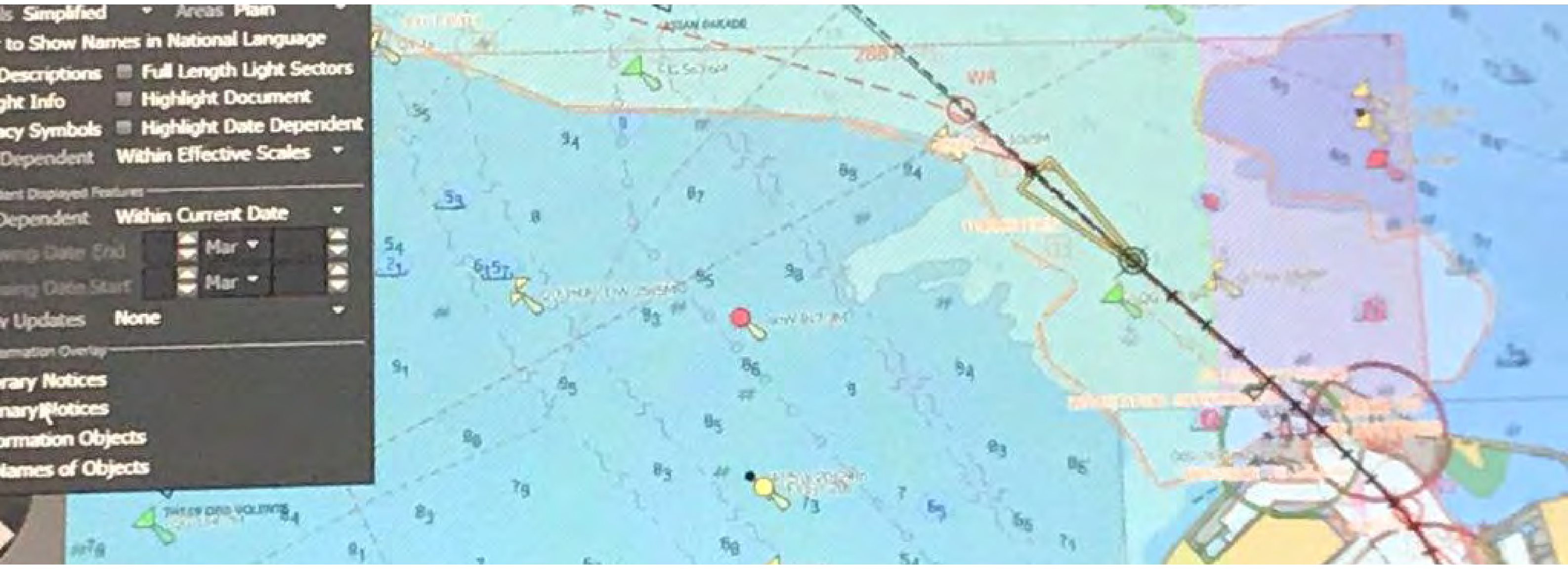


*Figure 12: Track without XTD in pilotage waters*

Implicit in the purpose of the planned XTD is that it should not be adjusted on passage. However, because navigational dangers outside the corridor can still be seen on the ECDIS and detected by the system's lookahead, navigating outside the corridor per se is not unsafe. It is just not deemed to be as safe as navigating inside the corridor as dangers could be missed depending on system set-up.

> *3/O, tanker: I don't always agree with those settings because when the planner is planning the passage, he doesn't know what is the best corridor that I might need from my route ahead on my watch.*

Variations were seen in the perceived importance and use of the XTD during passage. Some seafarers exited the XTD as a matter of routine, particularly where it was narrow (Figure 13). Others were reluctant to cross the XTD limit, particularly where the onboard SMS required precautions such as calling a second watchkeeping officer to the bridge or informing the master.


*Figure 13: Ship outside the narrow XTD*

### *Route Check*

Planners expressed that the primary method of route checking in ECDIS was by eye and, apart from a preference for larger screens when planning, they did not indicate any difficulties in this respect. Many also expressed that when planning the route, the automatic route check function gave confidence that dangers had not been overlooked during the visual check. However, whether a system's route check was used, and how it was used, depended on several factors including user training, ship type and trade.

> *C/O, passenger ship: … because we use the route every day we don't really read these warnings, but when we go to an area where we haven't been before or haven't normally been sailing, then we go through them.*

> *2/O, passenger ship: … we always use the same route, so when we've checked them once, we kind of don't check them again.*

> *Master, RO-RO passenger ship: I plan the route much like the paper charts. I zoom in and check every leg of the voyage. I do not like all those alarms. Then I use the EBL to verify distance to shore. I never use the automatic check. I do it manually … like in paper charts.*

The variation in how the route check was performed was mainly related to user knowledge of the planning functionalities, and specifically about how the ECDIS is designed to perform a route check. In the absence of in-depth knowledge about how the route planning functionalities were designed to be used, e.g. setting an expedient XTD, the planners were presented with a number of alerts, causing an increased workload and frustration, as most were either irrelevant, their source was readily apparent (e.g. the buoys in a buoyed channel), or the origin was not understood. This often resulted in the alerts generated being ignored (Figure 14). Planners with more in-depth knowledge of route planning functionalities also experienced similar difficulties, but to a lesser degree. Some planners investigated each alert, but this was usually a laborious process.

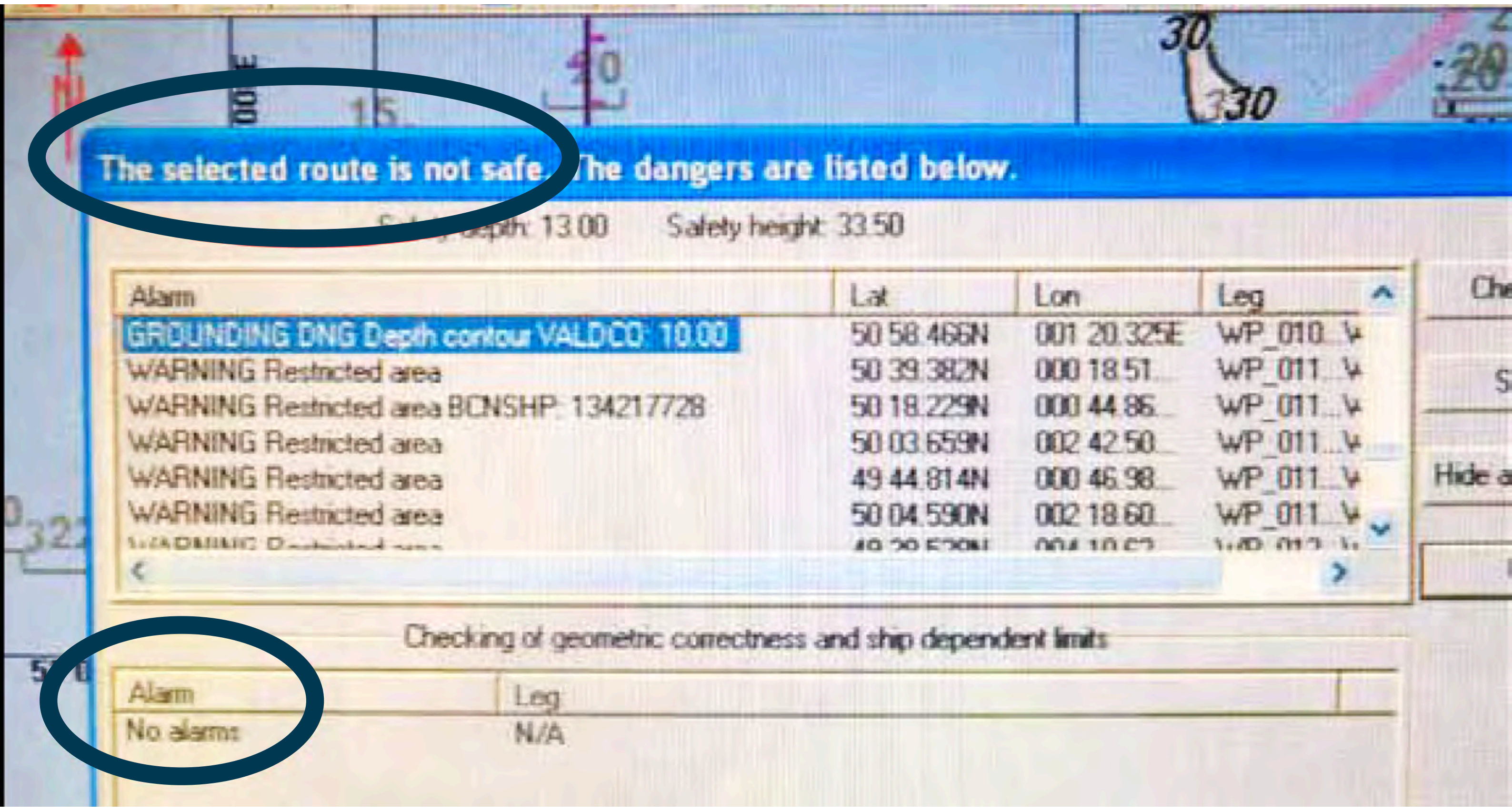


*Figure 14: Route Check page on ECDIS*

> *2/O, container ship: So, what I'm doing is taking care between each way-point that I don't have anything inside the route corridor or inside my cross-track error, however I set up and then I check from waypoint to waypoint, if I am satisfied I press route verification, and it might show me 1 million errors, which I acknowledge because I know I have checked.*

> *C/O, cruise ship: When you click on 150 warnings, of which 149 are all fine, you can miss something serious. The auto check is perfect, it will never miss anything, but it will pick up everything, more than needed.*

> *2/O, service ship: The automatic check doesn't really highlight anything you've not already seen when checking it yourself.*

None of the planners expressed concern at the reliability of the automatic check, although one complained of having to check ENCs at scales other than compilation scale to determine an alert source. There has also been at least one technical issue reported to a manufacturer where navigation dangers were not shown within an XTD, until the XTD was adjusted so that it did not cross into an adjacent cell.

> *C/O, cruise ship: If we get warnings and precautions doing the route check, you have to go and check those on the chart, perhaps it's a buoy in your corridor at the edge of the channel for example. You need to go through all the small things and check on the chart.*

> *C/O, passenger ship: … the ECDIS has a lot of checks and a lot of things that have to be okay for some, before you start a route, and you can make plenty of options and choices. And it can be really hard to find out if you have a fault at some point, to find out where it is and what it is causing the problem*

Different strategies were observed that were aimed at ensuring that voyage plans were effectively checked by persons other than the planner. In all cases, planners and masters were able to describe the routines in place, which on board some ships included the involvement of additional officers and the remote scrutiny by ship managers. One company had also introduced a specific 'review' stage between the 'planning' and 'execution' stages of voyage planning in its training and procedures.

> *C/O Cruise Ship: We have the four eyes principles so the second officer checks everything, then the master checks again, then the environmental officer checks it and signs it.*

> *2/O, tanker: So, you print out the passage plan, you verify the route then we all, the whole bridge team, have a passage briefing. The whole bridge team looks at the route and everybody has the option to comment we all see what we are expecting*

# DISCUSSION

> "The development of a plan for voyage or passage, as well as the close and continuous monitoring of the vessel's progress and position during the execution of such a plan, are of essential importance for safety of life at sea, safety and efficiency of navigation and protection of the marine environment."
>
> *IMO Resolution A.893 (21)*

The objectives of route planning in ECDIS are the same as they were with paper charts. However, the contributing factors to groundings associated with passage planning identified through accident investigation, and the study data, indicate that the way ECDIS is used to meet these objectives differs from paper chart practices in several ways.

In ECDIS, the input and manipulation of waypoints on a display screen replaces manually drawn course lines on small and then large-scale paper charts. This partial automation of the planning process has saved time, but it has also changed the purpose of the waypoint. A waypoint is now far more than the intersection of two course lines, it is the tool used to create and adjust routes, to vary the widths of the XTD and to assist with the calculation and plotting of turns. Consequently, the number of waypoints can exceed the number of course intersections, with multiple waypoints co-existing on a single course line. In addition, in planning through waypoint manipulation on a screen, ECDIS users do not interact with the charted information in the same way as planners physically drawing lines on paper charts of different scales.

ECDIS has also introduced safety parameters that must be set when planning. The 'safety depth', 'safety contour' and the XTD were intended by manufacturers to map across paper chart practices related to the separation of 'safe' from 'unsafe' water, and to meet the IMO performance standard requirements. However, the determination of these settings is open to interpretation, which has led to differing practices generated by vessels' trades but also by varying levels of navigation and ECDIS knowledge.

The safety contour attempts to automate the hand-drawing of a limiting danger line, but as described earlier, it is undermined by insufficient bathymetry. Although the 'safety depth' provides an in-built workaround to this problem, it is not wholly effective, and user workarounds are being adopted to try and improve the visualisation of the safe and unsafe water while maintaining alarm integrity. Difficulties associated with the application of the safety contour have resulted in industry bodies such as INTERTANKO placing such workarounds on a more formal basis. INTERTANKO's 'Guide to Safe Navigation' lists several approaches, each with advantages and disadvantages, which require different settings for the safety contour and the safety depth, despite being based on the same criteria, i.e. draught, height of tide and UKC requirements.

The use of workarounds by users to mitigate the insufficiency of depth contours in ENCs was almost certainly not envisaged during the formal safety assessments conducted before the mandatory carriage of ECDIS or by manufacturers. The use of workarounds to offset system shortfalls and achieve the objective of accurately defining safe water is not ideal, but it is well-intentioned and demonstrates system knowledge. However, that some ships during the study transited waters that were displayed as being unsafe because the safety contour 'didn't work', without the insertion of user-defined limiting danger lines, and/or not including the height of tide when calculating the safety depth and safety contour settings, potentially indicates gaps in either navigational knowledge or the ability to use the ECDIS, or both.

In an online survey conducted by INTERTANKO during 2019,[5] out of the 643 vessels that responded to the question 'How do you define safe water in shallow waters?' only 38% used danger lines or no-go areas.

> "To reach the discharging terminal, the vessel was obliged to cross the available SENC safety contour of 20m, calculated value of safety contour / safety depth = 11m. There was neither risk assessment carried out to cross safely the available safety contour nor limiting danger lines drawn to the calculated value of safety depth (11m)."
>
> *IVIQ Observation, 2018*

The variations in approach by planners in defining safe water can be explained to some degree by insufficient contour density and knowledge, but the different approaches adopted towards XTD parameters seem to be motivated more by competing goals. The XTD is not a tool used on paper charts, it is a legacy from equipment such as GPS receivers that was adopted by ECDIS manufacturers to enable indications to be given if a route is planned closer than a specified distance from prohibited areas and point objects.

> "Appropriate values for XTD and look-ahead vector must always be set, and reflect the characteristics of the vessel, the scale of the ENC cells to be used, with particular care exercised depending on the nature of the waters to be transited"
>
> *Admiralty Guide to the Practical Use of ENCs 2016 (NP231)*

Whereas industry guidance on the value set for the XTD tends to be ambiguous and most, but not all, SMS tended to use terms such as 'appropriate', 'realistic', 'correct' and 'intelligent' as rationales, it was evident during the study that the principal factor for many masters and planners was balancing the avoidance of too many alarms during the automatic route check and having sufficient freedom of movement when on passage.

> "The XTD margin shall be set as wide as possible (to allow sufficient time to react) but as narrow as necessary (to avoid unnecessary danger alarms when navigating in confined waters."
>
> *Extract from SMS*

5 Between March and May 2019 OCIMF and INTERTANKO conducted two online surveys of their members to collect information to assist in the development of recommendations on usage of ECDIS and preventing incidents.

Discussions with a manufacturer representative who was involved in the development and introduction of ECDIS within IMO and the IEC highlighted that the design intent was that the primary method of checking a route in ECDIS was the same as when using paper charts, i.e. by eye. The system's automatic route check was intended only to be an aid in this respect. However, the findings of accident reports and the views of ECDIS users indicate that there are problems associated with both methods.

The strategies being adopted for the review of plans by other planners and shore management reflect the fallibility of route validation in ECDIS due to both human and system performance. Visual checks remain vulnerable to human oversight with dangers particularly prone to being missed on small scale or overscale ENCs, and the automatic system checks being ignored due to the number and types of alerts generated. Even where the automatic system check is used, there is a risk of planners missing a safety critical alert among numerous more trivial ones.

# ROUTE MONITORING

## USER VIEWS AND ONBOARD OBSERVATIONS

***Watchkeeping***

During the study both user comments and onboard observations showed that ECDIS had contributed significantly to changes in watchkeeping practices. Watchkeepers were no longer required to run a path between the front of the bridge to look out of the window and the chart table to put a fix on the paper chart. Watchkeepers were now more tied to navigation consoles containing the ECDIS, radar and ARPA.

> “ *3/O, container ship: I think ECDIS has changed how people keep a watch. Before you would have been walking around, checking where you are. Now with the ECDIS, you can do your whole watch standing on one square metre, literally.*

***Customisation and tools***

On the ships visited, ECDIS configuration was the product of SMS requirements, user preferences and navigational context. The SMS typically prescribed minimum display and alert criteria for open, coastal and pilotage waters, but user preferences on other aspects of ECDIS configuration were variable. For example, although nearly all preferred the ECDIS display ‘north-up’ to align with the radar display – a configuration they had been taught and were used to and which some SMS required, the few using ‘head-up’ displays appeared to be equally comfortable.

> “ *Master, product tanker: North-up is what we are used to, I like it that way. This is natural, we were using charts that way.*

> “ *Master, LNG tanker: I have seen some officers who like course up, it’s a personal choice.*

It was also observed that users’ physical interaction with the ECDIS during open water and coastal passages tended to be limited to basic display functions such as zoom and scroll and the use of measuring tools (cursor, electronic bearing line (EBL) and variable range marker (VRM).

A vessel's position relative to its intended track on the ENC and the displayed ETA were frequently monitored. Very few users referred to or used the displayed position shown as latitude and longitude on the display, other than for completing the deck log. Some users expressed difficulty finding a balance between too much information being displayed, and too little.

> *3/O, cruise ship: For me, this setup is perfectly adequate. Some people use too little, some people use too many layers, you have to set it up how you like it.*

The ability to customise ECDIS to meet a vessel's characteristics, the navigational situation and personal preferences was seen by users both as a benefit and as a disadvantage. However, the ability to customise was sometimes not utilised due to menu complexity and users' unfamiliarity with ECDIS (Figure 15). This often resulted in a minimalist approach to system interaction with users reluctant to change system settings in case its original status could not be restored. A reluctance to change from a master's preferred configuration of ECDIS was also observed.

> *2/O, cruise ship: You can change so much on it and every time you go and sit down at it you have to check 1001 different things to make sure it is exactly how you think it is.*

The breadth and complexity of ECDIS configuration settings were reflected in the availability of checklists on board most vessels, created in order to ensure that key elements were not overlooked during watch handovers. Observations that ECDIS settings were not always discussed during these handovers and that checklists were occasionally completed and signed before any exchange had taken place, possibly reflected both the minimal changes made to system settings during passage and the complexity involved in retrieving the information required. It was noticed that whereas a great deal of other key navigational information was available on screens, such as the conning display, review of the ECDIS status required delving into several sub-menus, which required detailed system knowledge.

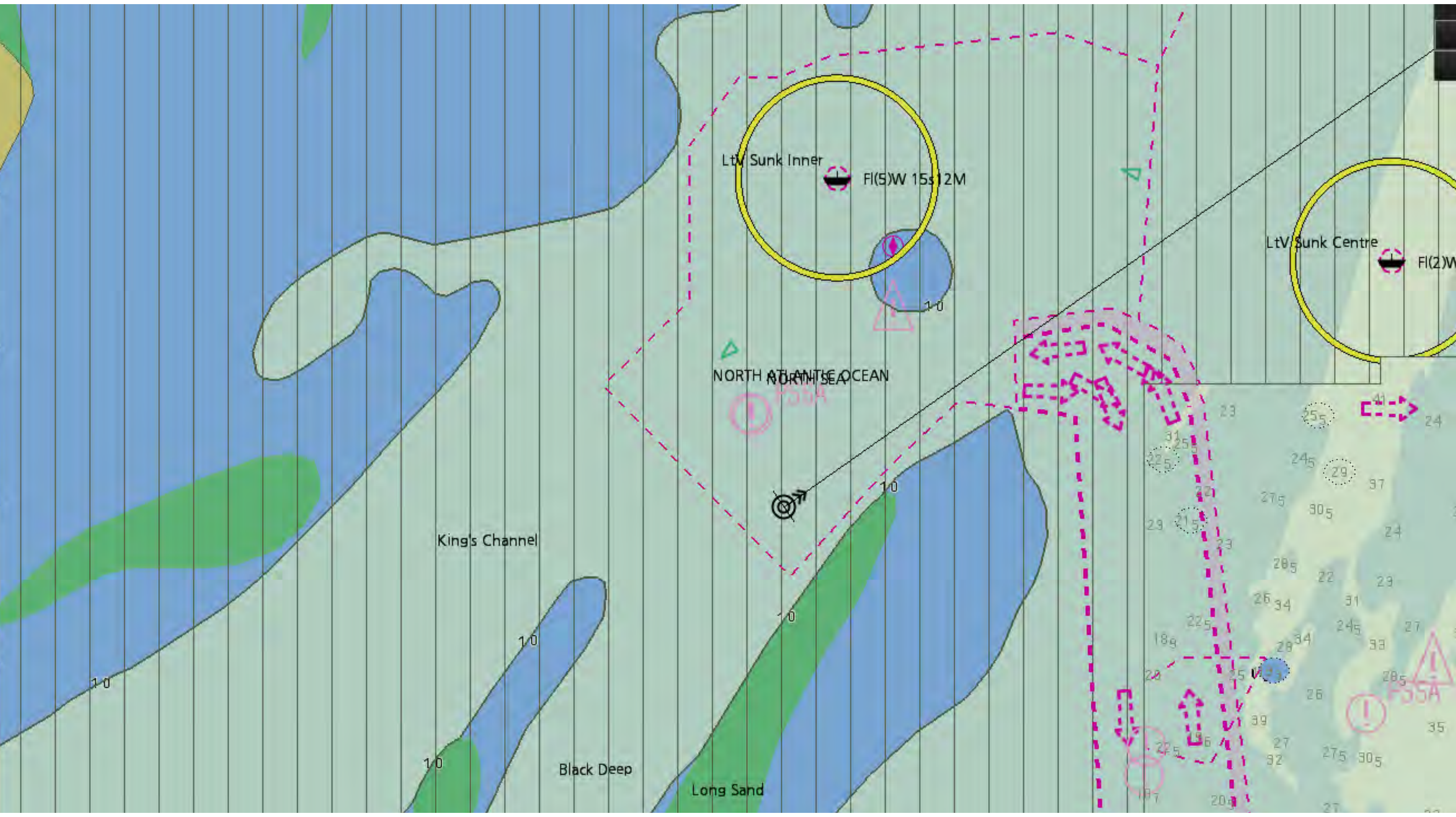


*Figure 15: Overscale Pattern (Jail Bars) indicating over expanded chart*

> *2/O, container ship: … usually we do not change too much because that leads to confusion.*

> *OOW, service ship: Now we have got these three set profiles. This makes sense, there are pros and cons but one of the pros is that you know what you have got, you come on watch and that's it, things haven't been taken off, so you haven't got to waste time going through checking everything.*

Masters in particular indicated that tools such as the vessel outline (Figure 16) and the predictor (Figure 17) have increased confidence, with some expressing that they were more comfortable operating in restricted visibility and manoeuvring in tight spaces with ECDIS than they were with paper charts. ECDIS has also enabled a vessel's position and bridge activity to be monitored internally from other onboard spaces, such as the master's cabin, and externally from ashore.

> *Master, container ship: … it is a fantastic thing, fantastic. It's made us more safe, made navigation easier especially in busy areas or approaching ports, even in bad visibility or restricted visibility.*

> *Master, ferry: … there is fog, you can see nothing, it is my eyes, and from my experience I trust the ECDIS.*

> *Master, container ship: I have a monitor in my cabin, so I can ask them on the bridge to activate something, the ETA or the speed. This is a good thing. It is just a slave monitor, I cannot use it, but I can see if the cursor is steady for 2 hours that nobody has touched the ECDIS.*

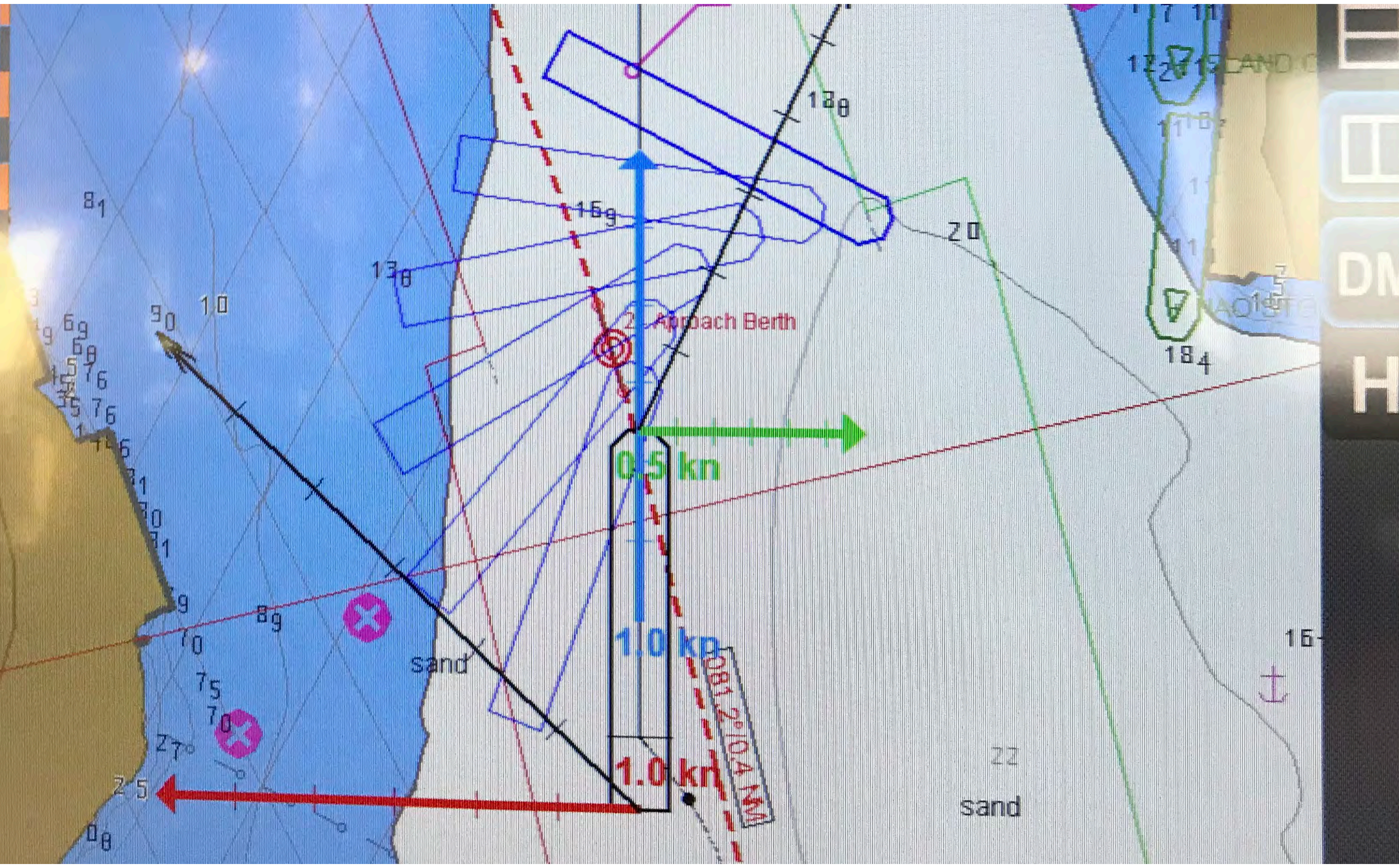


*Figure 16: Vessel outline + predictor*

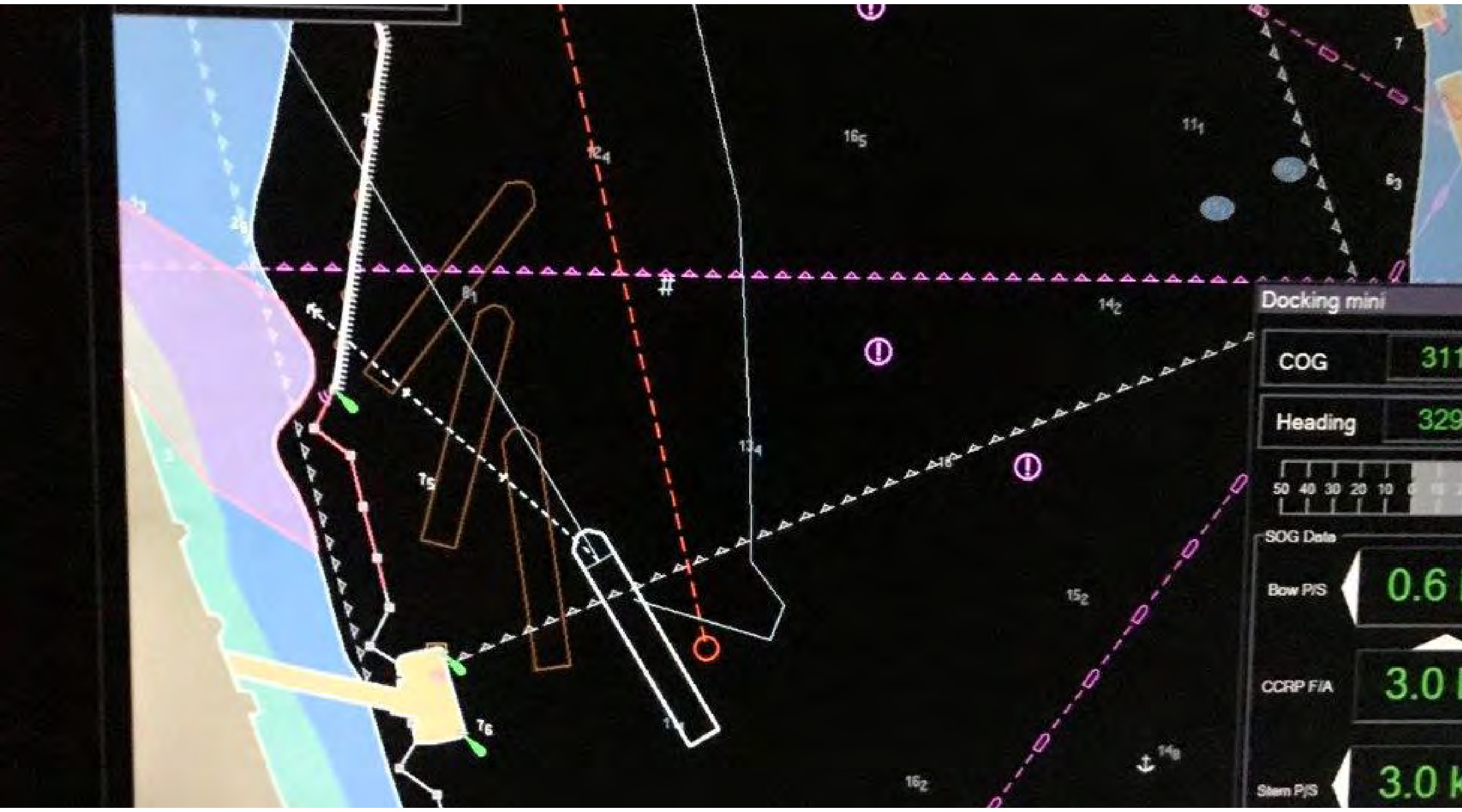


*Figure 17: Vessel outline + predictor*

### *Alerts*

When asked about problems related to route monitoring functions, most ECDIS users expressed that the high number of alerts the system generated created difficulties. Users did not explicitly distinguish between the different categories of alerts (alarms, warnings and cautions) or their different sources (for example AIS). Although some users expressed positivity towards the principal of alarms providing warning of navigational hazards, a need for expedient alarm management was also expressed. None of the users provided examples of an ECDIS alarm preventing an accident, and very few could recall a reduction in the number of alerts following the update of the IHO S-52 presentation library version 4.0. Although some felt that the provision of alarms was a positive measure, many expressed that the alarms were an annoyance, a distraction and a source of anxiety because of their incidence, and because they did not inform them of anything they were not already aware of or expecting. Accordingly, foremost among user wants were fewer alarms, audible alarms that were less annoying, and an acceptance that silencing audible alarms was a legitimate strategy.

> *3/O, car carrier: Other advantages are the alarms, the alarms are also a disadvantage but 90% it is an advantage and how I mean is the paper chart does not give you any alarm or warnings whereas ECDIS does give you the caution.*

> *Master, cruise ship: The alarms can be a good thing, but 99% of them are simply useless or false.*

> *2/O, cruise ship: … some of them are nonsense and are just a distraction and get on your nerves … in the end the alarms can be a problem with the operator, if you set them up properly they do not annoy you, but they help you, it is a matter of setup.*

> *2/O, cruise ship: I personally don't think the alarms are a big help because if I did proper planning before I know what is coming, so I don't need the alarms.*

> *2/O, service ship: … constant alarms. It's telling me things as a planner which I should already know and forcing me to acknowledge things for example I have just done, I don't need telling that I've just done it, I just done it.*

It was observed during the study that users typically had difficulty choosing system settings to minimise the number of alerts triggered by the bathymetric data when the ECDIS was basically used as a paper chart on a screen, and the crew had a rudimentary understanding of the functioning of the ECDIS. However, where the bathymetric data was sufficient to enable an effective safety contour to be set, and users were knowledgeable about the system, the alarms generated by the system were seen to be advantageous.

Most alerts were easily identifiable, but some were spurious and/or installation specific, examples of which included the grounding alarm activating in water significantly deeper than the safety contour, and when crossing cell boundaries. Separate ECDIS with similar settings were also reported and observed to provide different alerts at the same time. Some users also reported occasional difficulty in identifying the reason for some of the alerts due to the language used by the ECDIS software.

> *3/O, cruise ship: We have driven over deep sea contours at 50 m and we have had alarms to tell us we are passing over a contour yet the contour was not a safety contour for some reason but that system thinks it is, just that particular one.*

> *3/O, LNG tanker: … there are some alarms that we get which we don't know what they are, it looks like something is missing or something is not corrected or something has not been received but we don't find any solution and we don't know what to do. Most of these alarms are not listed in the manual we don't know what the causes are, we don't know what action we are supposed to take.*

> *Master, cruise ship: … you might see alarms coming up as WPS TLR what does that mean you have to go and look in the manual, does it have to be a little more in sailors' speak rather than abbreviations all of the time, these things are written by software people who have never been to sea.*

Instances where the meaning of the alert was unclear were seen to necessitate further investigation by the user in the system manual, or even contacting service agents ashore. Frustration was also evident at the frequent repetition of some alerts and their continued appearance on the display.

> *2/O, service ship: It's continually telling you that you're off track even though I have acknowledged it ... I've told it I'm happy, yes, I understand but it still alarming.*

> *3/O, tanker: The annoying thing is the alarms, especially if you are in congested waters with a lot of traffic you get some alarms which are not required such as AIS. You may have too many AIS targets around you, just get alarms and it keeps coming you acknowledge it keeps coming. Keeps coming back again, that annoys me.*

The frequency of ECDIS alerts predictably increased as the distance to charted navigational hazards, the safety contour and isolated danger marks decreased. In pilotage waters, the lookahead's detection of features and objects inside and outside the XTD, the reduced width of the XTD, the relatively short distances between course alterations and increased traffic density frequently combined to increase the frequency of alerts triggered by the different sources. In such circumstances, the bridge team was typically reinforced with more than one officer monitoring the navigation. Consequently, other than alerts informing the user about the status of the ECDIS (e.g. loss of GNSS input, gyro error), which were seen as important because they informed the user about an abnormality or fault that was easy to understand, the meaning and significance of other ECDIS alerts did not provide the bridge team with information they were not already aware of.

> “ *C/O, dredger: The most annoying is the course alteration alarm, that's the biggest one for us especially coming into a river where we have so many waypoints you get an alarm every time you need to alter course each leg may be only two cables.*

> “ *C/O, general cargo ship: … going in and out of port in very enclosed waters, a lot of targets getting collision alarms, making a sharp turn into a port, getting warnings about approaching land, shallow waters.*

On ships where navigational equipment was integrated, it was observed that alarms appeared on the separate systems as well as the ECDIS, e.g. AIS and radar closest point of approach (CPA) alarms. This duplication of alarms was also considered to contribute significantly to the workload.

> “ *C/O, container ship: Sometimes it's a little bit annoying when you are coming inside a port and four tugs approach and you have dangerous target alarms because four tugs are approaching you, they are not dangerous targets they are tugs approaching you to help.*

User responses to the high number of alerts varied during periods of high workload, e.g. in confined and congested waters where they were unwilling to switch attention from the primary tasks of position monitoring, manoeuvring and/or collision avoidance. These coping strategies ranged between the muting of audible alarms by various means, depending on the ECDIS model in use, ignoring the alerts, and cancelling the alerts as a matter of routine without investigation. To cope with this increased workload, the users thereby assumed a passive role of responding to alerts rather than actively controlling the ECDIS to avoid the triggering of alerts. Informal discussions with embarked harbour pilots highlighted that they were also concerned by the number of alerts generated and occasionally requested they be turned off.

> “ *Master, product tanker: … as you know we have the alarms muted in pilotage waters because it's a distraction when we are piloting.*

> “ *2/O car carrier: Alarms, useless alarms if you do not know how to set your alarms like arrival this is why I put it from monitoring mode to planning mode to get rid of the waypoint arrival and off course alarms and channel limits for me when we have a pilot on board these alarms are not necessary so I use the planning mode to get rid of those unnecessary alarms because alarms can be quite annoying and can be distracting so that is the solution I have.*

> “ *3/O, container ship: … usually every navigational officer neglects the alarms because by pressing the button all the time sometimes you don't take a really good look at what the alarm says, you just press the button.*

### *Accuracy checks*

Most ECDIS users were aware of onboard requirements to verify their vessel's GNSS position by alternate means and, although some had experienced GPS outages, very few had identified positional discrepancies while the GPS was functioning. Observations and interviews indicated that the frequencies of position verification stipulated in SMS were rarely, if ever, met, and the GNSS position was sometimes not verified at all. The use of other position checking/monitoring tools such as radar parallel indices was infrequent, and very few users saw the value in the routine of plotting visual and radar LOP, when radar image overlay (RIO) or chart underlay was available, or position could be verified by nearby visual references (Figure 18).

> *3/O, cruise ship: We do not plot positions regularly being honest with you.*

> *2/O, container ship: Parallel index, for me it's a distraction. For me there are plenty of other better tools than parallel index, I don't use that.*

In some cases, the required frequency of position fixing using LOPs was based on paper chart navigation (in one instance a three-minute interval was observed). As a result, the task was often seen as burdensome and of little value, particularly as it was not easily completed on some systems, and discrepancies seldom resulted. Plotting LOPs also restricted the users' ability to take on other, seemingly more useful tasks.

### *Radar and AIS integration*

Nearly all users of ECDIS integrated with radar felt that the use of RIO or similar was the quickest, easiest and most efficient means of verifying the displayed position. Those who did not have access to RIO, would generally have liked to have had it.

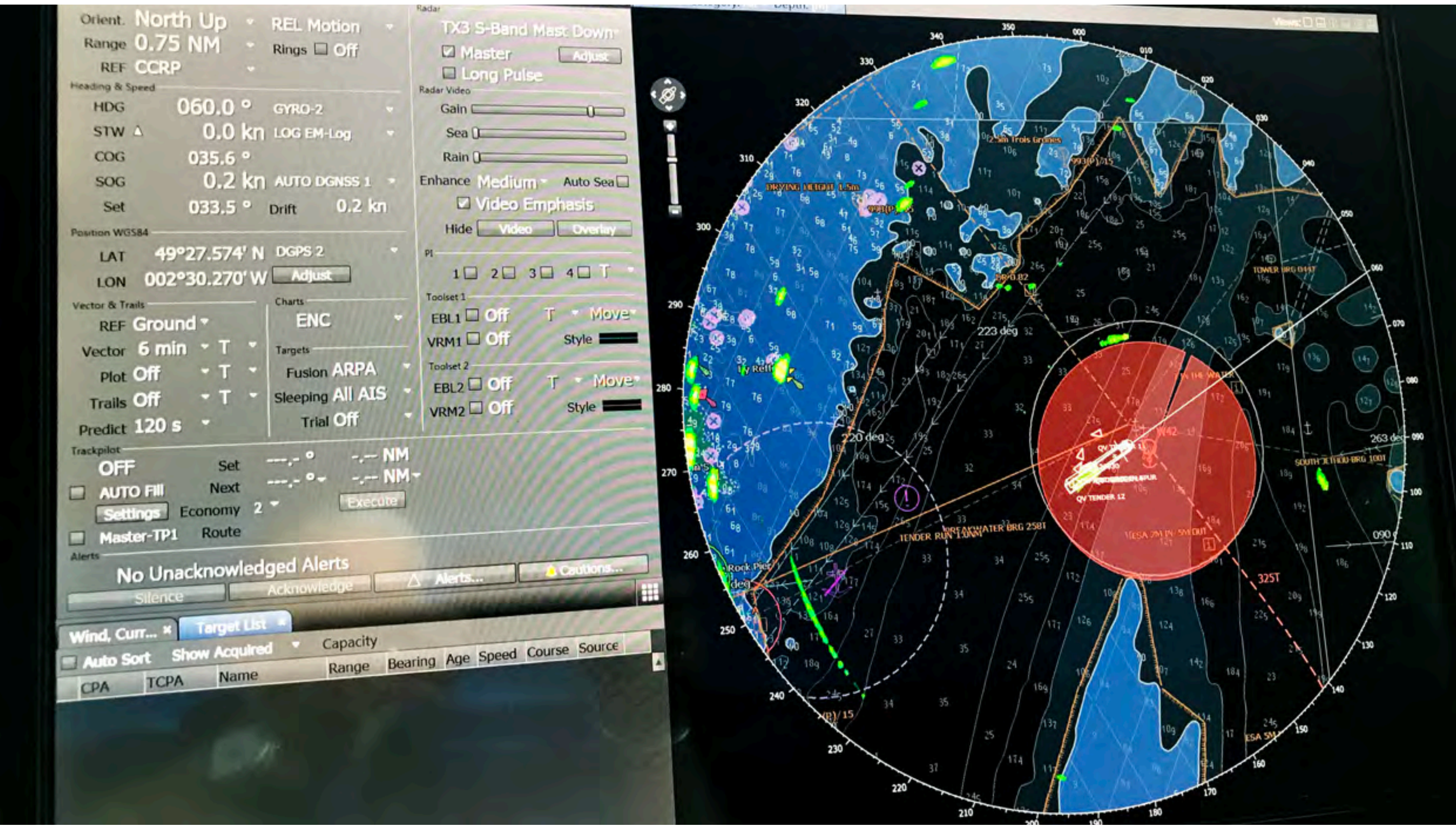


*Figure 18: Radar image overlay/chart underlay*

> *2/O, LNG tanker: The fact that you can quickly put a radar overlay is the most important thing for navigation, you are sure then that the ECDIS is showing the right position.*

> *2/O, ferry: Not having the radar connected is the most annoying thing.*

However, frustration was expressed by some seafarers that RIO was not always accepted by port state control (PSC) and vetting inspectors as a means of meeting Convention requirements.

> *Master, car carrier: Manual position fixing, which is a real issue if you go to Australia, they [PSC] expect you to put positions on the ECDIS.*

> *Master, cruise ship: The planner just looks at the screen and it's not just the radar it is also the ECDIS information all in one place so that definitely reduces workload between the chart table and the radar screen. You can just focus on the traffic while knowing where you are.*

Users of ECDIS integrated with radar and AIS generally felt that having the information on a single display improved situational awareness (Figure 19), but views on the use of the different information types, particularly AIS, were mixed. Nearly all saw ARPA as the primary tool for collision avoidance, with some adamant that AIS should not be used for this purpose at all. Others, however, commented that AIS added value with the benefits of knowing a vessel's name, destination and being able to see vessels in radar blind spots too significant to ignore.

*Figure 19: AIS overlaid on ECDIS display*

Study data confirmed that AIS in ECDIS was universally used as a means of lookout, and the extra information it provides over radar and ARPA was used to gain an overview of shipping traffic and to assist in decision-making.

> *Master, LNG tanker: It's for position fixing and collision avoidance as we have AIS overlays.*

> *2/O, container ship: It is primarily used for positioning, keeping the vessel on track, but also for an overview of traffic.*

> *3/O, container ship: ARPA is primarily used for collision avoidance, but the ECDIS is also useful, particularly with AIS targets. I can compare the AIS target on the ECDIS to the ARPA target on the ARPA.*

AIS overlay was seen to be a permanent fixture in ECDIS (and ARPA) onboard most ships in the study, and some users seemed to take AIS CPA/TCPA information at face value, using it to determine risk of collision – a behaviour reinforced by the data's general accuracy and users losing awareness of its derivation.

> *OOW, cruise ship: Probably everyone uses AIS more than they should.*

## DISCUSSION

As previously discussed, real-time positioning was seen by users as ECDIS' biggest contributor to safe navigation. However, the use of 'inappropriate' safety settings and chart scales, and the disablement of alarms identified in accident investigations; the routine and passive response to ECDIS alerts due to their frequency and perceived irrelevance; the claims of 'overreliance' at the expense of looking out of the window; and, position verification and criticism of the use of AIS (integrated with ECDIS) in collision avoidance are factors that potentially detract from the system's benefit overall during passage. Therefore, an understanding of the origins of such factors is essential if mitigating measures are to be identified.

SOLAS Annex 24 (Voyage Planning) states that the monitoring of a vessel's progress along the pre-planned track is a continuous process. Using ECDIS instead of paper charts for this purpose requires ECDIS users to be proactive towards display management. Whereas the information on paper charts was static and largely decided upon by cartographers, the information shown on an ECDIS is dynamic and can be customised. Inexpedient management of ECDIS display, safety and alarm settings can result in critical information not being displayed but also in too much information cluttering the display whereby the user loses the overview of the navigational situation. It can also result in excessive alerts or no alerts at all. Maintaining awareness of the navigational situation depends on the user's ability to configure the system and to determine what information is relevant and what is not. However, that ability is contingent not only on the user's knowledge of the system, but also on the functionality of the ECDIS, including the limitations of the underlying hydrographic data and the degree of freedom of action users are allowed.

The ECDIS user has no control over what and how some information is displayed. For example, a vessel's latitude and longitude is constantly displayed on a route monitoring page and cannot be removed, despite it hardly ever being used and the same information being available via the system's cursor.

Whereas ECDIS functionalities enable users to display or not to display other information (e.g. different hydrographic features), to change the way the information is displayed (e.g. ENC symbology) and safety settings (e.g. lookahead), it was evident during the study that a combination of menu complexity, a lack of system knowledge and prescriptive instructions in SMS discouraged users from customising the ECDIS to suit their own preferences. Although the prescription of ECDIS settings in the SMS was presumably introduced to mitigate system complexity and lack of user knowledge, which has proven to be advantageous for some users and has contributed to the development of best practice and consistency, it does not always contribute to effective alarm management in specific navigational contexts.

> "The handling, distribution and presentation of alarms play an essential role in facilitating situation awareness, support decision-making and improve the safety of navigation. The main purpose of alert management is to assist the bridge team in recognising an abnormal situation, identifying the origins of errors and deciding appropriate actions."
>
> *IMO, 2010*

In confined waters when a pilot is embarked, the visibility is good, and a vessel is in a buoyed channel, the attention on visual navigation is typically increased to the extent that the route monitoring functionality of the ECDIS, although accepted as a useful check, becomes a secondary activity. However, while the advantage of being able to continuously monitor a vessel's position remains unchanged, the number of alerts tends to increase. As a result, instead of ECDIS alerts assisting the bridge team in identifying abnormal situations and errors, a goal indicated by the IMO, they become a hazardous distraction by adding to the mental workload.

> "Survey respondents commented that many models generate a large number of alarms, both visual and audible, which lead to information overload and can either hinder crucial information or distract the officer of the watch from attending to more important matters."
>
> *Vu, Lützhöft and Emad, Frequency of use – the First Step Toward Human-Centred Interfaces for Marine Navigation Systems, The Journal of Navigation, 2019*

Ideally, in such navigational contexts where the number of ECDIS alarms and alerts increases, users are able to make continuous adjustments, having competence in all aspects of the ECDIS functionalities and actively controlling the system. This was rarely the case during the study due to alarms being triggered regardless of the settings (e.g. some isolated dangers), the inability to set meaningful safety contours, the proximity of hazards, menu complexity, user system knowledge and SMS requirements. The resulting extreme strategies that users adopted of either removing the alert/alarm by disablement or silencing, or normalising alerts and alarms by routinely ignoring or accepting them without investigation, tackle the problem of distraction in different ways but both defeat the underlying objective of assisting users to recognise an abnormal situation or an error.

In addition, although both strategies might be an effective measure when the focus on navigation is high, the findings of accident investigations (Table 1) indicate that this has not been the case during passage in coastal and open waters where navigational dangers still exist and the focus of lone OOWs on the navigation is likely to be influenced by the same numerous cognitive and environmental factors that affect watchkeepers using paper charts. It can be argued that it is during these phases of a vessel's passage, where the focus on navigation is relatively low key and watchkeepers are not looking at the ECDIS display, that the relevance of the audible alarms and the importance of investigating all alerts increases. Given the reduced frequency of ECDIS alarms and alerts in such environments, which makes them less of an annoyance and source of increased workload, their disablement or normalisation are difficult to understand.

"Another factor that appeared frequently in the free text answers was the crew's readiness to silence alarms without investigation due to 'alarm fatigue' caused by repeated alarm soundings for no apparent reason ... This is reflected in this chart where 45% of the respondents agreed that this happened. When this was analysed by the level of role, 44% of Masters, 41% of Chief Officers, 48% of Second Officers and 60% of Third Officers agreed, showing that this practice was prevalent among all ranks."

*Investigating the effects of bridge alarms, Shipowners, 2019*

It could be inferred that the increased confidence afforded to masters by ECDIS in restricted visibility and navigating in tight spaces, along with the widespread user view that ECDIS' biggest contributor to safe navigation is its real-time positioning are due to the fact, more often than not, the system is accurate. Users rely on ECDIS because it is generally reliable, and a warning is provided when GNSS is lost or its accuracy is reduced. As position fixing by alternate means when using ECDIS seldom identifies discrepancies, it is seen by some as a counterproductive procedure, particularly when requiring the manual input of LOPs. Only users that have experienced gaps and inaccuracies in the underlying hydrographic data in ENCs or the disruption of GNSS positioning without warning fully appreciate its rationale.

"GPS positions were not verified by plotting visual/radar position from her load port Basra till arrival Fujairah anchorage. Vessel relied on the GPS positions only."

*VIQ Observation, 2018*

As ECDIS was designed to replicate paper chart practices, and the use of paper charts previously defined the professionality of planners, the expectation to verify positions derived by GNSS by the plotting of LOPs or radar parallel indices was logical. However, the advantages of real-time positioning and the reduction of workload brought about by the integration of radar with ECDIS through RIO were initially not recognised. From a user perspective, such advantages need to be balanced with clutter and information overload, but this was not seen as a problem during the study.

Arguments encountered during the study against the use of RIO for checking position included that; a radar chart comparison is not a means of 'fixing', the radar overlay is fuzzy and not accurate enough, and that the use of RIO is difficult to audit. However, such arguments are just as applicable to the use of radar parallel indices. The need to 'fix' a vessel's position, which is promoted in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended, (STCW), and in SOLAS Chapter V Annex 24 (voyage planning) was approached in different ways. Some onboard SMS seen during the study referenced the use of 'traditional techniques' while others accepted the use of RIO. Industry guidance was also found to be contradictory with the ICS Bridge Procedures Guide promoting the use of 'traditional fixing techniques', whereas INTERTANKO's 'Navigation and ECDIS Guidelines' endorse the use of the radar overlay/ENC underlay. Both the use of radar overlay for position verification and 'traditional techniques' for position plotting in ECDIS are endorsed in OCIMF's Recommendations on Usage of ECDIS and Preventing Incidents.

> "Where the radar display is integrated with an Electronic Chart Display and Information System (ECDIS) the practice of parallel indexing continues to enable the navigator to monitor the ship's position relative to the planned track and additionally provides a means of continuously monitoring the positional integrity of the ECDIS system. "
>
> *UK Maritime and Coastguard Agency Marine Guidance Note 379 (M+F)*

> "When using ECDIS, appropriate usage code (scale) electronic navigational charts shall be used and the ship's position shall be checked by an independent means of position fixing at appropriate intervals."
>
> *STCW VIII/1/Part 4. Art. 47*

To clarify the situation in the short term, there is a strong case for both SOLAS, STCW and other IMO instruments which are significant references for flag State, port State and vetting inspectors to be revised to include position verification as well as position fixing, and to promote the use of RIO as an accepted means of the latter when using ECDIS. Arguably, position fixing using LOPs is relevant only where ECDIS and radar are not integrated or where positional discrepancies due to, for example, datum misalignment, GNSS loss, inaccuracy or 'spoofing' have been experienced. In the longer term, the potential simultaneous use of different GNSS systems (GPS, GLONAS, Galileo and BeiDou) and the development of terrestrial navigation systems such as R-Mode, are likely to improve positional accuracy and resilience, as well as making it possible for position verification to become an automatic function within ECDIS.

# SYSTEM DESIGN

## USER VIEWS AND ONBOARD OBSERVATIONS

*Overview*

User views on ECDIS design and functionality were found to be dependent on their experience and familiarity with ECDIS models of different ages and types, varying degrees of system integration and the use or otherwise of paper charts. On ships with a high level of bridge system integration, the users did not clearly distinguish between the ECDIS and the other bridge systems. They viewed the bridge equipment as one system and thus talked about system drawbacks that were not necessarily related to the ECDIS and position monitoring per se. For example, they would address the problems related to collision avoidance when using radar overlay. On ships with a low level of system integration, users viewed the ECDIS as a separate system with its own benefits and drawbacks with comparisons made to paper charts or other ECDIS.

*System Differences and Complexity*

Users with experience on a variety of ECDIS models were able to talk about the differences between them, pointing towards features that were better or worse compared to their current system. Differences cited included system speeds and capabilities, menu logic and complexity, physical interfaces, the ways visual information was displayed, display locations on the bridge, the audibility of alarms, terminology and the inclusion or omission of specific functions. Nonetheless, other than isolated instances involving older systems, most users indicated a general satisfaction with their current system, albeit with recurring caveats that not all its functionalities were used and that training and familiarisation (and re-familiarisation after breaks from use) were essential. References were also made to the younger users being more comfortable with ECDIS technology than older users, but this was not universal with a number of experienced masters being seen to take a great interest in the equipment.

> *2/O, car carrier: ECDIS will do more than we require. We use it for the basic things, that is the way we are working but we can go beyond with ECDIS. It is a beautiful tool.*

> *2/O, cruise ship: … they're fairly straightforward it's one of those after a week back on board you are always on it, we were redoing the track earlier on and it was a little slow but was just getting back into it, it's the same way when you go back home and you get on the telly and go into the Sky menu take some time to find a channel.*

> *Master, container ship: This one is actually quite user-friendly, you just need training.*

> *C/O, cruise ship: … in the first few weeks it is very difficult, some are hidden and you have to open the settings, in the end it all makes sense as everything is in a certain place but you have to find these places inside. In the beginning it is not very user friendly but once you get used to the system it is very interactive.*

That ECDIS users utilised only some of the system's functionalities was reflected in responses connected with ease of use, system complexity and potential improvements. Generally, it was only when trying to use unfamiliar functions or seeking information that was not usually required that user difficulty was experienced. Users thought such problems could be resolved by fewer ECDIS types, more standardisation and single operation controls.

> *Master, bulk carrier: … the menus are so easy unless you don't know where to find something.*

> *C/O, car carrier: The menus are very easy to navigate, there are very limited menus so for basic use you need five or six items and then you can use everything you need. Once you learn what you need to find.*

> *C/O, car carrier: You now have a cell phone with 50 apps and you have no idea what most of them do, so why should ECDIS be different.*

When problems were encountered, many users did not attempt to resolve problems by looking at the ECDIS operator manuals. Instead, they preferred to ask a colleague, usually the officer responsible for passage planning.

> *2/O, car carrier: … but the other officers if they have alarms or anything happens with the ECDIS they call the second mate and I will be the one who has to look at the pages and the operator manual.*

> *2/O, LNG tanker: it (the operator manual) is very big and sometimes hard to find what you want. A lot of information. I usually ask the navigating officer if I have a problem.*

> *3/O, ferry: I was trying one day to try to find the guard zone, if you take the manual and look for guard zone it is not there – it has the option of lookahead, but it is not written guard zone.*

> *2/O, container ship: … it's much simpler than any computer game in my opinion. It's not such a problem for the younger generation.*

ECDIS operator manuals were generally seen to be very comprehensive but many users expressed that they often contained too much information. The manuals were often a last resort when problem solving, with some users finding shorter user guides more useful. The manuals were hardly ever used for general self-learning, although some of the users that did refer to them felt that the documents did not include sufficient explanations or detail, for example, about functions such as the ECDIS predictor.

> *2/O, cruise ship: … we only really get the manuals out now if we get the odd alarm that we're not expecting, or something is not working correctly. No, I don't think I've ever pulled the manual out for this system or for most of the systems I have worked with. I'm assuming that they are in the cupboard there with the rest of the manuals.*

### *Difficulty and Annoyance*

As discussed previously, the most common difficulty cited by voyage planners was the inability to define safe water using the safety contour. This occurred regardless of ECDIS model and resulted in calls for increased contour density and dynamic tidal data. Frustration was also observed when users experienced difficulties when searching for information on some charted features, such as the depth of a dredged channel. As also discussed previously, the most common source of annoyance among all users was the large number of ECDIS alerts experienced in route planning and route monitoring, which added to the mental workload and were distracting. Other than the alarms (and alerts), the interface that attracted most user comment was the ECDIS display. Older users with experience of paper charts generally expressed that the screen was too small for both route planning and monitoring.

Many of these users, particularly those responsible for route planning and those required to sit continually in front of the ECDIS display when on passage, felt that bigger display screens should be permitted, justifying their want by comparing the size of an ECDIS display screen relative to paper charts, ergonomics and fatigue.

> *C/O, cruise ship: … the screens are small and if you are sitting for three or four hours in front of the screen it can kill you*

> *2/O, LNG tanker: One day I would like to see for the planning station a chart table with a large flat screen that you can plan on.*

> *C/O, cruise ship: For monitoring the route it is way too small, paper charts were huge and you could monitor.*

> *3/O, cruise ship: The ECDIS is easy to look at it's just become normal, most people have a mobile phone and you have Google maps it's not an ECDIS but it is a chart it is just become normal to look at a chart on a screen.*

Other general comments regarding ECDIS screens concerned picture clarity and layout (resolution, font/symbol sizes and colours), along with unfavourable comparisons with other equipment such as 'tablets' and portable pilot units (PPU), that were deemed to be more capable. Criticisms of specific ECDIS displays were related to the integration of interfaces on the bridge (positioning and sunlight), environmental customisation (dimming and day/night modes) and display ratios (the respective areas given to chart, radar and text information).

> *LNG tanker 2/O: The night mode settings are terrible, there isn't a proper night mode. If I go on night mode it's useless, one big nothing. You have to set it in dusk mode and with the brilliance you can adjust it. Night mode, sooner or later they will have to do something with it.*

> *Service ship 2/O: I prefer to switch into night mode because it's just too bright otherwise although it can be hard to distinguish between the safe and unsafe water compared to the daytime mode.*

> *Cruise ship C/O: We do not need 50% data on the screen we need 90% of the screen to be PPI and 10% of the screen to be data.*

> *Master, cruise ship: … dinosaur standards restrict us from using all the technical potential which we have nowadays – comparing the CIQ pilot PPU, which operates on an Ipad Pro – much better screen clarity in comparison to the ECDIS. This has to be solved as we move towards the S100, this is the sort of screen we want to have an official ECDIS the colour is one thing but the display and the information cluttering and the resolution, we have to come out of the Stone Age in regard to display resolution.*

User comments on other system interfaces also tended to be ECDIS model and installation specific and included issues connected with software (older software versions, system glitches), hardware (capacities of hard drives and processors) and physical interfaces (trackballs sticking or not working and keyboard layouts making manual inputs difficult).

> *“Master, cruise ship: … it depends how easy it is to actually make a position fix on the ECDIS. Doing this with a trackball can be a bit of a headache so how good is the system at motivating people to make a manual position if it is so complicated.*

> *“2/O, LNG tanker: I use the planning station because it has a proper keyboard, the keyboard with the actual ECDIS is not great for any plotting, it’s easier to go to the planning station.*

Among the variety of differing functionality issues identified by users were manual functions requiring several attempts to input (e.g. chart updates and the cutting and pasting of routes), inaccurate outputs (e.g. the displayed ETA and predictor), inconsistency (e.g. the erratic display of a ship’s position and ARPA changing to course-up as the vessel crossed a cell boundary), slow system speed (e.g. slow to zoom in and out) and system limitations (e.g. the inability to skip waypoints, plan and monitor alternate routes, and simulate harbour manoeuvres).

> *“2/O, product tanker: … you have to be very precise in clicking the line, you have to hit it precisely otherwise it will not move and sometimes this takes time.*

***Reliance***

When talking about the disadvantages of ECDIS, reliance or ‘overreliance’ was a criticism levelled at ECDIS use by some masters, managers and deep-sea pilots, who typically associated the behaviour with ‘not looking out of the window’.

> *“Deep-sea pilot: There’s a great tendency to focus on the ECDIS and not focus on the bridge windows.*

> *“Master, cruise ship: That is the only thing, overreliance, the guys can spend all day looking at the screen rather than looking out the window.*

However, onboard observations identified that users did not spend all their watches looking at the ECDIS or multifunction display, despite some sitting by them almost continually. When crossing the Bay of Biscay and other open areas, they did not frequently look at the ECDIS; there was nothing to look at and the display was virtually static. Users became focused on the ECDIS only as the amount of information displayed increased, and the situation became more dynamic. Although some users expressed that they were prone to looking at the ECDIS too much, others felt that having the ECDIS allowed them more opportunity to look out of the bridge windows because they were not having to frequently move to the chart table to look at, or put a fix on, a paper chart.

> *“3/O, cruise ship: If you are arriving at port, if it’s a long pilotage, you may find yourself looking at the screen as opposed to looking out of the window; when checking the buoys, you might get a bit engrossed.*

> *“Service ship 2/O: I definitely look at the ECDIS more than I did the paper chart, I mean you only go into fixed position or check for dangers but I’m looking at ECDIS nearly all the time and watch. Probably spend as much if not more time looking out the window with ECDIS than I did with paper charts. When you’re at the console you can look at the screen and straightaway look out of the window and see where something is.*

# DISCUSSION

One of the principals of a human-centred approach to design detailed in ISO 9241-210-2019 (Human-centred design for interactive systems) is that the design is based on an explicit understanding of users, tasks and environments. In this respect, ECDIS was designed to replace paper charts by enabling the replication of the manual practices undertaken by users on paper charts through automation or, where necessary, enabling them to be undertaken using digital media. However, although discussions with manufacturers indicate that seafarers were involved in the design process, ECDIS design seems to have been shaped principally by the technology available and through compliance with technical standards, rather than user tasks and environments.

These technical standards, which have expanded significantly over the last two decades, aim to satisfy the IMO performance standards, but they allow the numerous manufacturers freedoms of choice regarding, among other things, hardware capacities, operating systems, menu structures, interfaces, behaviours, and additional functionality. Differences between ECDIS models with respect to these aspects of system design resulted and has led to calls for standardisation from industry bodies such as the Nautical Institute. Such action indicates that the performance standards alone were not an adequate basis for efficient and user-friendly system design, and that the specific and detailed user training that is required to operate individual systems effectively is impractical for users that are expected to swap between different systems.

"Significant variation between systems and equipment produced by different manufacturers has led to inconsistency in the way essential information is presented, understood and used to perform key navigation safety functions. Improved standardization of navigation systems will provide users with more timely access to essential information and functions that support safe navigation."

*MSC.1/Circ. 1609 -Guidelines for the Standardization of User Interface Design for Navigation Equipment*

IMO guidelines to promote the standardisation of vocabulary, symbols and icons, grouping and patterns, and locations of information in ECDIS are seemingly a positive step in satisfying user 'wants'. However, although during the study, ships' officers expressed irritation with the varying ECDIS' interfaces, that very few voiced difficulties when switching between different systems possibly reflected that moving between different systems was an infrequent occurrence, or that differences in system interfaces and behaviours could be quickly accommodated.

As most users also expressed satisfaction with their current model drawing on comparisons with older models, it could be argued that ECDIS design is ongoing and improving. However, while this might be the case at the practical level of usability, the users' minimalist approach to ECDIS functionality, difficulties related to tackling system problems, the frequency and irrelevance of alarms, the difficulty in defining safe water with the safety contour, behavioural aspects such as alarm normalisation and disablement, and 'reliance', indicate that more significant underlying issues exist.

> "Usability – extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."
>
> *Ergonomics of human-system interaction – Part 210: Human-centred design for interactive systems (ISO 9241-210-2019)*

Further important aspects of human-centred design concern decisions related to which functions are automated, and which are not, and how the user can work best with the machine to achieve the overall goal. With ECDIS, the mandating of the continuous plotting of a ship's position in the IMO's performance standards was an automation previously proven in ECS and is seen by users as ECDIS' foremost benefit. However, other automated and semi-automated features of route planning and monitoring that came with ECDIS, such as the alarms on crossing the safety contour, deviation from route and approach to critical point, along with the large number of visual indications, have largely been unpopular. The annoyance and difficulty expressed by users regarding these features, and the workarounds and coping strategies they have had to develop in mitigation, suggest that the decisions to automate such elements appears to have been taken solely on the basis that it was technologically possible to do so, rather than an adaptable blending of human and machine capabilities. Such automation was well-intended and is potentially highly beneficial in the context of a lone watchkeeper at night in coastal waters. However, its consequences within other contexts, such as pilotage, do not appear to have been fully probed or tested using varying degrees of system integration, different manning regimes, and differing levels of bathymetric data.

> "Basing such [design] decisions solely on those functions the technology is capable of performing and then simply allocating the remaining system functions to users is likely to result in an ineffective design."
>
> *Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems [ISO 9241-210-2019]*

That some automation within ECDIS is not effective and that some manual tasks such as the drawing of limiting danger lines, the insertion of text, the planning of parallel indices, and the plotting of LOPs are more difficult using ECDIS than paper charts, perhaps contribute to users tending to use only the minimum ECDIS functions they need to get the job done, ignoring what is difficult if at all possible. The overall system design requires users to engage significant cognitive resources to use its functions, and increases the possibility of poor decision making leading to an accident. Seafarers are subject to a wide variety of factors that can negatively affect their performance during navigational tasks, including motivational factors related to the difficulty of using poor equipment. If using navigational equipment requires high levels of cognitive resource, it can be highly inefficient for users who, as accident investigation reports indicate (Table 1), are frequently focused on watchkeeping issues or influenced by other competing pressures. Unless ECDIS is designed to be usable to support naturalistic decision making and its functions are easy to use, then a minimalist approach is set to continue, and safety may be compromised.

The origin of other human behaviours connected with ECDIS use that were encountered during the study arguably also rests to some degree within the system's design with:

- The 'normalisation of alarms' through silencing or ignoring, reflecting the number of alarms and alerts which add little or no value and the absence of an effective alert philosophy or hierarchy;
- Overreliance resulting from the system's overall reliability;
- 'Not looking out of the window', a behaviour probably resulting from the way information is displayed which makes the interfaces very 'addictive' or require significant mental effort to use.

With regard to the display of information, screen size, the trade off on the display between chart data and other data, and the efficacy of the night modes between systems were all criticised to varying degrees by users. However, while many users called for larger screens, few were able to verbalise their concerns, other than that they found small screens difficult to use. To some extent, this difficulty is being mitigated by the increased use of larger 'back of bridge' screens that are used for planning and briefing. However, the use of larger screens for position monitoring, which might potentially mitigate against overreliance and not looking out of the window, is still seemingly not permitted. As a result, an onus is placed on the user to mitigate this poor integration of ECDIS with bridge watch-keeping tasks by developing practices that differ to those previously used with paper charts.

> "A significant weakness of ECDIS is the size of the chart display. Compared to a paper chart this can be minuscule – the standards allow the display area to be as small as 270 x 270 mm. Unless used sensibly, ECDIS can create a tendency for the user to develop 'tunnel vision'. It must therefore become natural to not only be regularly zooming in and out and scrolling the chart but also to retain a good mental image of the general layout of the area in which the ship is traversing."
>
> *Dr. Andy Norris, Seaways, January 2012*

In the future, these practices might include the use of 'head-up' rather than 'north-up' displays to reduce the mental cost of transferring between looking at the ECDIS display and looking out of the window, along with scanning pattern techniques.

> "Overreliance on ECDIS should be avoided, particularly if detrimental to the keeping of a proper lookout."
>
> *ICS Bridge Procedures Guide 5th edition 3.11.3*

Criticism and admonishment of the behaviour of ECDIS users with regard to 'overreliance' and 'not looking out of the window' are unlikely to be successful strategies, if the source of these behaviours lies in the system's design, rather than the user. To be successful, however, any future developments in ECDIS design would benefit from task-based studies undertaken by user-experience experts who are fully familiar with the problems associated with displays and other system interfaces.

Although procedures generally have a role in mitigating the consequences of ineffective system design, user-centric engineering strategies to manage mental workload and help ensure that all information sources are utilised are likely to be more effective. It is also important that engineering approaches factor in a full cognisance of the wider socio-technical system, as outlined in IMO Human Element resolution A.294, when developing ECDIS. In addition to larger screens for monitoring, suggestions for system re-design coming from this study included, but were not limited to:

- A reduction in the number of alerts accompanied by an effective alert hierarchy, which the introduction of the Bridge Alert Management (BAM) system seeks to redress;
- The development of automatic position verification checks using multiple alternate systems, which should be possible with the operationalisation of more GNSS;
- The continued development of 'through window' augmented reality displays.

# 4 CHANGE OF SKILL SET

# INTRODUCTION

To use ECDIS effectively, OOWs and voyage planners need to have a comprehensive understanding of the system's capabilities and limitations and, equally important, an understanding of how the ECDIS has changed the traditional navigational practices based on paper charts, including the division of work among bridge team members. Nonetheless, a common contributing factor highlighted in casualty reports (Table 1) is a lack of knowledge about the ECDIS functionalities and their limitations. This knowledge gap is not only found among the individual users, but also within the bridge team as a whole.

> "The electronic chart display and information system was the primary means of navigation on board L'AUSTRAL, yet the operating crew were not fully familiar with the capabilities and the limitations of the equipment and were not making best use of it."
>
> *L'Austral, TAIC, 2018*

> "Accurate user-defined settings are essential, if an ECDIS is to provide the level of navigational safety expected of it. This accident shows how ineffective it can become, if the settings that have been entered are incorrect."
>
> *Molly Manx, TAIC, 2017*

> "The safe and effective use of ECDIS as the primary means of navigation depends on the mariner being thoroughly familiar with the operation, functionality, capabilities and limitations of the specific equipment in use on board their vessel."
>
> *ABFC Roebuck Bay, ATSB, 2019*

The interviews and on-board observations therefore, in part, aim at shedding light on how ECDIS users are prepared to meet the new challenges introduced by the ECDIS. Users were therefore asked questions regarding specific system features and were encouraged to express their opinions of the benefits and drawbacks of using ECDIS. The objective of the conversations was to gauge the users' technical familiarity and training, and to gain an understanding of how the ECDIS has changed navigational practices.

# USER REPONSES AND OBSERVATIONS

## TECHNICAL COMPETENCE

During the interviews and observations, users were engaged in conversations about specific ECDIS features such as the system's presentation library, XTD, safety settings, route planning functionalities, etc. From those conversations it stood out that there is a large variation in the level of knowledge about the ECDIS functionalities, which influences the users' view on the ECDIS. The users are generally confident in using various functionalities in day-to-day navigation on the type-specific ECDIS the ship is equipped with, e.g. plotting waypoints, changing and loading routes, zooming in and out, etc. However, during the interviews the majority of users typically found it difficult to expound generic ECDIS features such as safety settings, alerts, sensor inaccuracies, symbology, integration with other bridge systems, etc. Apart from ECDIS functionalities the users also demonstrated a gap in knowledge about the underlying hydrographic data in ENCs, e.g. accuracy, survey, symbology, regional differences, etc.

On ships with an ECDIS displayed on a MFD within an INS, it was noticeable that the majority of users expressed superficial knowledge about the extent of the integration and how it affected the functioning of the system, i.e. what sensor integration is necessary for the ECDIS to function and what sensor input is only integrated and displayed for convenience. The absence of detailed knowledge about the system integration is an indication that the users viewed the ECDIS as a standalone system helping the user solve the specific task of establishing the ship's position. It was less seen as a system comprising several separate sensors with different benefits and drawbacks. In the day-to-day navigation, their limited knowledge about the INS did not pose a problem for the user. It would, however, hinder efficient diagnosing and problem solving when parts of the system malfunction. Few users had been trained for, or familiarised with, such contingencies.

This lack of technical knowledge makes the voyage planners unsure about, e.g. how the ECDIS calculated wheel-over points, why some alerts were activated during sea passage, and how the course predictor worked. Additionally, users were found to have difficulty using the type-specific ECDIS features such as menus or sub-menus, and they were reluctant to change various system values while performing route monitoring, e.g., changing safety depth, changing layers, etc., because they had doubts about what effect it might have. Within the bridge team, it was typically the user responsible for passage planning who had the most comprehensive understanding of the type-specific ECDIS. The other users usually turn to this person when the system is not performing as expected. Although a few planners demonstrate a high level of system knowledge, the absence of system knowledge is found among planners across nationality, age, ship type and the ship's trading area.

> *2/O, Ro-Ro ship: And still sometimes I have to sit down and realise I do not know the place now with that information I need, or that setting I need to change – and I can spend too long time trying to find it, I think, and sometimes I've just kind of given up and waiting for someone else to come back and ask them.*

Misconceptions about basic ECDIS functionalities, the underlying hydrographic data and how the system is intended to be used are manifested by a scepticism towards various functionalities due to a lack of understanding, e.g. alerts, while at the same time having unfounded confidence in the reliability of information displayed.

Such contradictions indicate that users are able to use the ECDIS as a paper chart on a screen but find it difficult to demonstrate that they have an expert understanding of both generic and type-specific ECDIS features. It was thus found that inferior knowledge about the ECDIS functionalities seems to make both the planner and the general user prone to using the ECDIS as a paper chart on a screen, thus only using the most basic ECDIS functionalities during route planning and monitoring.

In relation to handling contingencies, e.g. loss/freeze of the system, loss of GNSS input, radar overlay, etc., it was noticeable that most users did not have any formal training in how to detect, diagnose and respond to system malfunctions. On board some ships, drills had been developed to practice elements of ECDIS malfunctions, but these tended to be conducted as table-top exercises due to a reluctance by masters to disconnect equipment, e.g. GPS. Few users recognised a difference between system malfunction and navigational inaccuracies, i.e. all inputs were functioning as expected but the radar and GNSS positions varied due to inaccuracies in the ENC.

When a malfunction occurs the user often has to take full control of the ECDIS, e.g. revert to applying paper chart practices on the ECDIS screen. The implication of this for manual take-over from the ECDIS is that the user who has to act quickly can only do so on the basis of minimum information. The user will not be able to make decisions based on wide knowledge of the ECDIS' state, until they have had time to check and think about it. This will inevitably lead to a delay in response from the user, once it becomes apparent that the ECDIS is not displaying accurate and reliable information. Having competencies in diagnosing system malfunctions (e.g. positional offset) requires knowledge about the particular system setup and the wider navigational bridge system integration. Knowledge which is absent without comprehensive training. When breakdowns occur, the majority of users were found to rely on having access to technical personnel from ashore to make the necessary adjustments or repairs. During the interviews, users could not provide specific details about the nature of the malfunctions they had experienced or how the system was restored by the technical service providers.

> “*C/O, Ro-Ro passenger ship: I've spent a lot of time with the operator's manual trying to figure out what the various faults it was giving meant, and it was not always possible to find the fault it was coming up with in the operator's manual, so we have quite a lot of email correspondence with the developer.*

We thus found that a lack of in-depth knowledge resulted in a scepticism towards various ECDIS functionalities, accompanied by a frustration with the time-consuming tasks associated with diagnosing and rectifying the faults.

## TRAINING AND FAMILIARISATION

During interviews, users were asked about the type and duration of their generic ECDIS training and familiarisation. However, many found it difficult to recall the details of their training, e.g. when and where they had undergone generic ECDIS training, or what the syllabus included. Thus, it has not been possible to compile reliable data about the content of the generic training the users had received or to analyse whether or not their generic training provided them with the necessary knowledge to make them proficient in obtaining an in-depth understanding of ECDIS features. Even though the planners could not recall the content of the course, they expressed concern that the duration of the generic course was too short to give them a sufficient understanding of the ECDIS. Some users described the course as overly focused on using the ECDIS in a simulator and learning about the practicalities of using the ECDIS, and less on classroom lectures about system limitations, inaccuracies, etc.

Given that the course is typically 40 hours in duration and not necessarily aimed at the type-specific equipment they would use on their ship, the planners relied on continuous use of the onboard ECDIS to become familiar with the system.

> *2/O, container ship: I … was promoted to second officer, so I've never really since school time been working with all this planning part, so that is something to get to myself, to get more familiar with ...*

Most users interviewed had received type-specific familiarisation on the particular equipment they had on board. It was found that there are different approaches to familiarisation, ranging from reviewing and signing a checklist with little interaction with the ECDIS, receiving e-learning courses, attending type-specific training on board or at an ECDIS course provider, to bespoke training in system use in bridge simulators. Users generally preferred hands-on familiarisation with the presence of an instructor, as e-learning platforms were often ineffective due to problems with connectivity, system speeds and the users having to complete familiarisation while on leave.

Users described how the familiarisation process progressed as the ECDIS was used under various circumstances, depending on their job function. However, data from the interviews suggests that once the user is confident using the functionalities necessary to solve daily tasks, the formally structured learning process seems to stop. When presented with a novel task the user may, for example, struggle to find the right menu/sub-menu when looking for a specific system feature. The implication is that the type-specific ECDIS requires continuous use for the user to gain system familiarity, which makes the ECDIS stand out compared to other items of bridge equipment, e.g. the radar, GPS, AIS, etc. which are more standardised and less complex.

> *2/O, container ship: I think the problem with that [generic training] was, when I received the training and got on board and was actually using it, the time between that was too long.*

> *2/O, passenger ship: And on-board familiarisation, we have this check-list – general, usable for all the vessels; not that specific – and it was more like we have to find it out on our own. There was not like a video guide or a training, which I think would be very nice in the beginning.*

> *3/O, Ro-Ro passenger ship: In our system we have a six-month interval where we have to go through it all again, by using a checklist. I think this could be a very good idea …*

These accounts of training and familiarisation could explain why some users interviewed only had a rudimentary understanding of ECDIS functionalities and limitations, although they were confident using the basic system features and were able to carry out the day-to-day navigation.

The users who stood out as having expert knowledge had undergone comprehensive generic and type-specific training offered by the shipping companies and were experienced with the system used. These are companies that primarily operate cruise ships and have in-house training developed for their specific trade and navigational strategies, or companies that operate tankers and are focused on having elaborate navigational procedures and extensive familiarisation to meet the requirements set out by the charterers.

# NAVIGATIONAL PRACTICES

From interviews and observations, it has been found that the navigational practices when using the ECDIS were polarised between users with some degree of technical knowledge about ECDIS functionalities and those with less knowledge, resulting in differences of opinion about what is the most expedient way to use the ECDIS. E.g. should users be utilising the automation, responding to alarms and notifications, or should they primarily be manually checking the accuracy and reliability of the ECDIS? This polarisation is enhanced by the generational gap between OOWs with experience using paper charts at sea and OOWs who have only used ECDIS. It stood out that users had mixed views about what constituted best practise, which reflected a dichotomy between those who advocated a distrust in the system and the need to constantly check its outputs, and those who trusted and used the system with confidence.

Across the spectrum of ECDIS use the differences in navigational practices were primarily found to depend on the degree of system integration and the individual's own levels of training and familiarisation. On ships with a high level of bridge system integration (e.g. HSC, cruise ships), established practices among different users were typically found. These practices were implemented by the company during training and familiarisation, whereas on ships with a stand-alone ECDIS (e.g. ferries, bulk carriers) there was significant variation among the users' responses to what constituted a best practise of ECDIS use.

> "Many users comment on the lack of usefulness of this feature [parallel index lines] since the installation of ECDIS became mandatory. As ECDIS allows the display of the ship and the surrounding environment in real time, this comment shows that users rely more on ECDIS to carry out the purposes of the PI function."
>
> *Ergonomics of human-system interaction — Vu, Lützhöft and Emad, Frequency of use – the First Step Toward Human-Centred Interfaces for Marine Navigation Systems, The Journal of Navigation, 2019*

During the study the on-board ship procedures were reviewed and it was found that ship operators have mitigated the mixed views on what constitutes ECDIS best practices by introducing more or less elaborate procedures for utilising the ECDIS functionalities. At one end of the range, a minority of ship operators, primarily cruise ship operators, have recognised the necessity of enhancing the users' knowledge and skill set. They have gone a step further by raising the rank of the planner to 1/O-C/O and implementing procedures and training regimes that, in addition to technical training, include the development of navigational practices that depart from the traditional paper chart navigation to support their particular needs. At the other end of the range, operators rely solely on a compliance-based approach to training and proceduralisation of navigation, based upon existing procedures for paper chart navigation that offer little support for the users.

# DISCUSSION

Comments from users indicated that ECDIS use was in line with the general proliferation of technology within society. Younger seafarers did not usually voice the benefits and drawbacks of paper chart practices as they had little or no experience of them, and most viewed themselves as more adept than older seafarers at using ECDIS. Such views were supported by observations of masters delegating junior officers to change ECDIS settings rather than doing it themselves – a behaviour almost unheard of with regards to radar, with which they are familiar. However, nearly all the masters of paperless ships in the study stated that they would not want to revert to paper charts now that they were familiar with ECDIS.

> *Master, bulk carrier: Now that I know how to use ECDIS, I would choose ECDIS over paper charts, I do not want to go back.*

Paper chart navigation practices have continuously evolved with the introduction of new technology, e.g. with the increased reliance on radar and GNSS in conjunction with paper charts, resulting in a common understanding of what constitutes best practices. These practices have been promulgated and established by various industry publications and through training offered by navigational colleges. Given that paper charts were common to all ships, it was possible to have more or less standardised practices across different ship types, trades, etc. With the implementation of ECDIS, paper chart navigational skills will continuously diminish as newly appointed bridge officers will not have experienced using paper charts, and because the skill set required for using ECDIS is significantly different.

> "Since ECDIS is not only an electronic version of a paper chart, but a more comprehensive navigation and information system, complete mastery of its resources and knowledge of limitations is of crucial importance for safe navigation."
>
> *Vu, Lützhöft and Emad, Frequency of use – the First Step Toward Human-Centred Interfaces for Marine Navigation Systems, The Journal of Navigation, 2019*

> "However, the differences between the two media are considerable. This has been recognised by the International Chamber of Shipping (ICS) in its Bridge Procedures Guide, which states: Navigation with ECDIS is fundamentally different from navigating with paper charts. As a consequence, the safe use of ECDIS requires the mariner to be appropriately trained and appropriate bridge procedures to be established."
>
> *CFL Performer, MAIB, 2008*

For example, information presented on paper charts is in a standard format (title, north-up, symbology, colours, scale, latitude and longitude, cautions, update log, source data diagram, etc.) and cannot be changed or manipulated, i.e. 'what you see is what you get'. The only link between the chart and onboard sensors is the user when fixing a ship's position and generating a dead reckoning or estimated position. Information displayed on ENCs in ECDIS is not fixed. It requires customisation to suit local conditions, user preferences and to operationalise system tools intended to facilitate safe planning and warn of dangers, i.e. 'what you get is what you set'. In addition, real time positioning and projection has reduced the need for manual interaction, and integration with radar and AIS has centralised essential information on a single display.

While the training and use of paper charts navigation has resulted in established training regimes and best practices across the industry, ECDIS has not triggered similar consequences. The process of developing and maintaining competency to operate a constantly changing system and the development of best practices are still in their early stages and ongoing, as the industry is learning how the ECDIS and other integrated systems are most expediently used across the spectrum of ship types, trades, bridge integrations, etc. During the study it has been observed how the introduction of ECDIS has changed navigational practices with significant variation across the various maritime contexts, and on any given ship the users also encounter uncertainty and competing opinions about what constitutes best practice.

Such a shift in practices changes the OOW's core skills. The processes of determining the position of the ship manually by plotting positions on a chart, and monitoring progress along the route by looking out the window and at the radar, are now done automatically. The automation of plotting position and route monitoring via alarms and notifications has changed the OOW's core skill from producing information about the navigational situation to being a manager and monitor of automated bridge systems. This shift in core skills does not only require knowledge about the technical functionalities and limitations of ECDIS, but also calls for an understanding of how the ECDIS functionalities are utilised in an expedient manner. It calls for an understanding of what constitutes best practise in a given navigational context.

As navigation becomes increasingly automated, the more crucial the user's ability to monitor and control the ECDIS and its integration with other systems becomes. While automation has eliminated some manual tasks, the OOW is still left with tasks that have not been automated, e.g. changing the safety settings when approaching port to avoid unnecessary alarms, or evaluating the quality of the hydrographic data. The reduction of the manual workload has thus not simplified the navigational tasks, but has rather made it a more complex work process, requiring a higher cognitive workload and competence when interpreting the continuously changing display while controlling the system's accuracy and reliability. It is therefore not only vital to have expert knowledge about the functionalities of the type-specific system, but equally important to be skilled in determining how to utilise the ECDIS functionalities depending on the navigational context in conjunction with the radar and the AIS.

> "Products from different companies often have a different "look and feel", and seafarers face difficulties familiarising themselves with new equipment when moving between ships."
>
> *Vu, Lützhöft and Emad, Frequency of use – the First Step Toward Human-Centred Interfaces for Marine Navigation Systems, The Journal of Navigation, 2019*

When using ECDIS, new knowledge and skill demands are imposed on the user. The findings from the interviews indicate a general absence of system knowledge among ECDIS users across nationality, age, ship type and the ship's trading area. Findings which are supported by several accident reports (Table 1). Consequently, the ECDIS stands out as safety-critical equipment which is subject to substantial variation in terms of knowledge about the system functionalities and its limitations.

Interviews with ECDIS course providers and the review of the IMO model course syllabus[6] indicate that the current ECDIS training regimes are primarily focused on providing the course participants with knowledge about system functionalities and limitations, and less about how and when that knowledge is to be applied, e.g. in a given situation, are user-defined limiting danger lines required? What settings should be used for the XTD and lookahead? Or, how should the user divide his/her attention between the ECDIS, the other equipment and looking out the window? This variety of use suggests that the ECDIS is still in an implementation phase, regarding how the ECDIS is to be used on board, making a standardised training regime difficult to define.

Recognising that the level of competency needed in the use of ECDIS is dependent on the level of system integration, ship type, trading area, manning, etc., it is questionable whether a generic course and type-specific familiarisation will meet the training requirements necessary to become an expert in various navigational contexts. Furthermore, as the ECDIS constantly evolves it becomes necessary for the individual user to continuously manage their knowledge and skills in using the ECDIS. It is thereby brought into question whether the current generic course syllabus as set out in the IMO model course 1.27 and system familiarisation is sufficient for reaching proficiency in a complex safety-critical navigational system, and whether on the job training and self-tuition are realistic or sensible options for the "navigators to be given a reasonable opportunity to become familiar with the shipboard equipment, operating procedures and other arrangements needed for the proper performance of their duties, before being assigned to those duties[7]".

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6 IMO Model course – Operational use of Electronic Chart Display and Information Systems (ECDIS), 2012

7 STCW A-I/14.2

# 5 CHALLENGES TO SHIP OPERATORS

# CHALLENGES TO SHIP OPERATORS

"The ongoing safe and effective use of ECDIS involves many stakeholders including seafarers, equipment manufacturers, chart producers, hardware and software maintenance providers, shipowners and operators, and training providers. It is important that all these stakeholders have a clear and common understanding of their roles and responsibilities in relation to ECDIS. "

*ECDIS – Guidance for Good Practice (MSC.1/Circ.1503/ Rev.1)*

In addition to its users, ECDIS also challenges other maritime industry stakeholders at different levels. Operationally, pilots encounter multiple ECDIS with differing degrees of integration. They are no longer able to refer to ships' paper charts and during the study, although some harbour pilots seemed familiar with some ECDIS models, most were seen to rely on a mix of visual references, radar or PPUs. On the other hand, the deep-sea pilots carried their own laptop computers which displayed their intended voyage plans on raster charts.

At the regulatory level flag States have had to decide on policies covering areas such as back-up arrangements, training and examinations; PSC and vetting bodies have had to set out strategies for inspection; ECDIS manufacturers are having to respond to calls to improve reliability and usability; and trainers, some of whom have no practical experience with ECDIS use, have had to develop ways to convey ECDIS knowledge. It has been a steep learning curve for all, not least the ship operators, who have experienced and were still experiencing challenges connected with the transition from paper chart to paperless navigation.

The response to ECDIS implementation among ship operators has been variable. During the study, some operators of ships that were required to carry ECDIS had opted to keep paper charts as the primary means of navigation, whereas others, including some operating ships to which the ECDIS carriage requirements were only optional, had gone paperless. Resistance to ECDIS navigation was generally linked to familiarity with paper chart navigation, distrust in technology, distrust in officers' competency and scepticism towards new ways of working.

> *Ship operator: You can't remove information from a paper chart, you can't delete information in error.*

Ship operators who had embraced ECDIS were generally positive about the system, citing such advantages as reduced chart costs, greater flexibility in ENC holdings and supply, and reduced workload for the planner. The disadvantages expressed generally mirrored user views regarding system complexity, generational differences and training. In one instance, a ship operator had delayed the introduction of ECDIS due to resistance from its masters, all of whom were established paper chart practitioners.

> *Ship operator: Overall a valuable tool for the modern navigator, however, it has several implementation problems, the most important here being the human interface approach – not having a unified conceptual menu across all manufacturers, thus not being user friendly like a tablet-based program for example.*

> *Ship operator: ECDIS is a positive step, something that younger crew expect, not so much the older ones.*

> *Ship operator: We have positive feedback overall, particularly from the young generation, while the problems are mostly related to old crashing hardware and difficulties encountered with licensing, obtaining ENC permits and keeping the ENCs up to date using various ENC providers.*

Ship operators spoke of several management challenges accompanying ECDIS, including:

- selecting which system to install,
- whether to use ECDIS as the primary means of navigation,
- whether to go completely paperless,
- coping with the differing preferences of shipowners and differing flag State requirements,
- technical issues concerning reliability and performance,
- system upgrades (e.g. Version 4.0 of the IHO presentation library) and ENC updates,
- the unavailability of ENCs in some regions,
- the development of best practice and onboard procedures, and
- documentary issues concerning Form E and Type Approval certificates.

However, the challenge that stood out among ship operators was ensuring bridge officers were competent in ECDIS use, which frequently led to positive comments on ECDIS being accompanied by caveats such as “when it’s used right”.

> *Ship operator: Personally, I feel basic training does not go deep enough.*

> *Ship operator: As DPA I get stuck between the money men and the need to train.*

Some concern was expressed by most ship operators at the variability of navigation training provided to cadets by maritime institutions, which resulted in significant variations in knowledge among seafarers with the same certificate of competency. Ship operators also commented on the differences in the quality of generic ECDIS courses, which was seen by some as a transitional aspect. However, the major concern of ship operators was the suitability and effectiveness of the different forms of ECDIS familiarisation. Although large operators with in-house training facilities and bridge simulators were able to ensure their bridge officers were trained to a company standard, others were reliant solely on computer-based training (CBT) and onboard use. Most ship operators were cognizant that more or better training was required but were uncertain as to what form it should take.

> *Ship operator: The lack of training and familiarisation is systemic and needs to be addressed on an industry level.*

ECDIS is a different type of equipment than e.g. radar, GPS, echo sounder, etc. as it is subject to continuous changes that create problems for the hardware, e.g. when chart and route data is increased, or when system software is updated. The problem of having older generations of ECDIS on board became apparent when the new IHO ECDIS presentation library (V4.0) was introduced in 2017. The performance of some older ECDIS models was so adversely affected that some ship operators had to have them replaced, because they did not have the hardware capacity to run the system update. Keeping up with the latest development of the ECDIS therefore requires a different maintenance strategy to other bridge equipment that is not subject to the same system changes.

Problems associated with software upgrades were acknowledged by the IMO at MSC 101 in June 2019 in tasking of its NCSR sub-committee to revise and improve *ECDIS – Guidance for Good Practice (MSC.1/Circ.1503/Rev.1)* with respect to ECDIS updates and type approval requirements. However, there are many other aspects of ECDIS use for which consensus remains outstanding, with flag States and other bodies taking differing approaches. These include: ECDIS 'back-up', where some flag States allow paper charts; safe return to port arrangements, where differing views are found on paper chart requirements; methods of familiarisation training; the use of radar overlay and other aspects of integration; the carriage of spare parts and cyber security. ECDIS – Guidance for Good Practice was intended *'to have ECDIS-related guidance within a single circular, which could be easily kept up to date without duplication or need for continual cross-referencing*'. However, further frequent reviews of its content, based on the experiences and feedback of all stakeholders, will be extremely important in ensuring clear and unambiguous understanding of the requirements for ECDIS carriage and use in an increasingly technology-based environment.

# 6 CONCLUSIONS

# PURPOSE

In this study MAIB and DMAIB set out to investigate ECDIS use from the perspective of practitioners with the aim to generate an understanding of the practical application and usability of ECDIS against the intention of ECDIS standards and design. In this respect, the study has been successful, largely due to the frankness and openness of ECDIS users reporting how ECDIS were being used. The views of the various other stakeholders and data from published accident investigation reports, technical standards and academic papers and industry articles connected with ECDIS also provided invaluable alternative perspectives and insights.

# FINDINGS

## SPECTRUM OF USE

1. The wide spectrum of ECDIS use, from paperless ships with a high level of bridge system integration to ships where ECDIS was simply used as a paper chart on a screen has resulted in the gradual divergence of the way ships are navigated. User perspectives and navigational practices were thus found to be highly contextual.

## OVERALL BENEFITS

2. Across the spectrum, users identified the ECDIS' main contributions to safe navigation as the reduction in workload and the increase in situational awareness resulting from real-time positioning.

3. ECDIS' reliability and the integration of ECDIS with other navigational systems were seen as benefits. Users rarely experienced significant malfunctions, and they were generally found to trust both the information provided by ECDIS and its technical reliability.

4. Some ECDIS functionalities were seen to reduce the manual labour of updating charts, plotting routes using waypoints, etc., but these functionalities were not necessarily viewed as contributing to safe navigation per se.

## CHALLENGES

*General*

5. The distraction of alerts and alarms, particularly during pilotage, lead to coping strategies including; not setting alarm parameters (e.g. safety depth, guard zone and lookahead), muting of alarms where possible, and physically disabling alarm sounders when electronic muting was not possible.

6. The pictorial depiction of 'safe' and 'unsafe' water was seen as impractical in many instances. This has resulted in both 'official' and 'unofficial' workarounds in an attempt to optimise the display to the best extent possible, or the safety contour being ignored altogether.

7. The number and types of alerts generated during automatic route checks diminished the value of this facility for many users. Some simply ignored or bypassed the route-check functions, preferring to rely solely on a visual check of the route. Planners that attempted to use the route-check felt it was easy to miss safety critical alerts among numerous, less significant, warnings and cautions.

8. Interface and menu complexities increased cognitive workload, particularly in busy environments, which resulted in users becoming overly focused on ECDIS to the detriment of other sources of information.

### *Technical Standards and Capability Shortcomings*

9. The IMO ECDIS performance standards do not consider the differing contexts of ECDIS use, any variability of paper chart practices that existed before the system's introduction, or the potential consequences of integration the system has facilitated. They also do not account for the limitations of hydrographic and bathymetric data available.

10. Users' minimalist approach to ECDIS functionality, difficulties related to tackling system problems, the frequency and irrelevance of alarms leading to alarm normalisation and disablement, the difficulty in defining safe water with the safety contour, and behavioural aspects such as 'reliance' and 'not looking out of the window', indicate there are significant underlying issues with ECDIS design.

11. The unpopularity of many alarms and alerts related to ECDIS functions among users suggests that the decisions to automate such elements appear to have been based on technical possibilities rather than an adaptable blending of human and machine capabilities and that the consequences of such automation were not fully tested in varying contexts with differing degrees of system integration, different manning regimes, and differing levels of bathymetric data.

12. Residual manual tasks are frequently more difficult to complete using ECDIS than on paper charts. ECDIS design requires significant cognitive resources to use its functions, and unless ECDIS design is improved to better support naturalistic decision making and its functions are easier to use, then a minimalist approach is set to continue, and safety might be compromised.

13. The variability and poor fidelity of hydrographic data in many regions result in the automated use of the safety contour to define safe and unsafe water, and to alert the watchkeeper to potential grounding hazard, working sub-optimally.

14. The consequence of the above shortcomings is that current ECDIS rely heavily on user intervention to achieve 'safe' navigation. This is not unexpected, but it indicates that current ECDIS, bridge integration and hydrographic/bathymetric data fall well below the standards needed if navigation processes are to be further automated.

### *Influence on Practice*

15. ECDIS has expanded the bridge watchkeeper's role in maintaining the safety of a vessel by increasing the data available that requires management, assessment and interpretation. To do this, watchkeepers must acquire skills through training – training that differs considerably to the training associated with paper chart navigation.

16. Although the intent was for ECDIS to replace paper charts, its introduction has significantly changed navigation practices. Passage monitoring has been made simpler through continuous position plotting, but passage planning has become more complex if the full benefits of the system are to be realised. Digital waypoints can be used in multiple ways and have significantly greater utility than their paper chart forebears, and automated alarms and alerts can be set to warn the watchkeeper of impending hazards or deviations from the plan. However, users reported that when the parameters underlying the alarms and alerts either are not, or cannot be set appropriately, they are, at best, of limited value and, at worst, can be a significant burden and distraction.

17. Some traditional navigation practices have not transitioned well to the digital world. Inputting radar parallel indices, limiting danger lines or lines of position and writing text notes are cumbersome tasks, which deter many users from their use. Conversely, a digital equivalent to plotting lines of position, the radar image overlay, has yet to become fully accepted as a legitimate means of position verification.

### *Competency/Training*

18. The study found a broad range of competence amongst the planners interviewed and observed. Most reflected that the task of plotting the route itself was simpler, and those with paper chart planning experience felt the digital system was easier and quicker than the process of transferring tracks from large scale to small scale paper charts. Thereafter, skills and competence varied widely. Some planners did not understand the difference between safety contour and safety depth, which perhaps raises questions about the quality of the training they had undertaken. Those that did understand the relevance of the various safety settings were seldom observed exploiting them to maximum advantage, and many defaulted either to the standard settings articulated in the company SMS, or to settings they had found worked satisfactorily on previous passages.

19. The study found that watchkeepers were confident in utilising basic ECDIS functionalities aimed at providing an overview of the ship's position and the progress of the voyage. These functionalities, which automate the simple, repetitive and time-consuming tasks previously done on paper charts, were appreciated and well-understood by the users. However, the majority of users were found to have little in-depth understanding of how to appropriately configure and adjust ECDIS functionalities to match differing navigational contexts, some being reluctant to manipulate settings for fear of being unable to restore the settings they were currently using. The users generally held the view that these functionalities added to their workload, and they were found to rely on a compliance-based approach to navigation, based on the procedures for paper chart navigation.

20. Watchkeepers remain at standby to take over and manually perform navigation should the automated functions fail, for whatever reason. However, their paper chart-based navigational knowledge and skills are eroding, which is reducing their ability to act effectively as a backup to the ECDIS.

21. Few watchkeepers used the onboard manuals for trouble-shooting when confronted with a navigation task they could not complete, instead deferring to the expertise of colleagues, usually the ship's designated passage planner. Passage planners themselves felt that the ECDIS training they had undertaken had not prepared them well for some tasks, and many cited difficulties with chart updates that could only be resolved in port or with shore-based support. Very few users were curious to learn more about the systems they used, and some were completely relaxed that the ECDIS, 'like a mobile phone', would have functionalities they would never need, and therefore did not need to know.

22. The development of best practices was found to be in its early stages as the industry is learning how the ECDIS and other integrated systems are most expediently applied across the spectrum of use. The variety of navigational practices found during the study suggests that the ECDIS is still in an implementation phase, in terms of how the ECDIS is to be used on board, making a standardised training regime difficult to define.

23. It is questionable whether the current generic IMO model course and type-specific familiarisation are sufficient for users to reach proficiency across a range of navigation tasks that include: voyage planning, voyage plan approving, passage monitoring, system updating and trouble shooting. Further, some type-specific familiarisation involving on-the-job training and computer based self-tuition, while expedient, is not providing the training required to become an expert user across the spectrum of system configurations and navigational contexts.

# PATHWAYS TO IMPROVEMENTS

## BASIS FOR CHANGE

On completion of the draft of this report, copies were sent to industry organizations and bodies with a stake in ECDIS. The stakeholders were invited to review the draft report, and based on the study's findings, identify areas in which the ECDIS 'experience' and its contribution to safe navigation could be improved. This study highlights ECDIS' contribution to safe navigation through its real time continuous position plotting. However, while some findings point towards specific problems encountered by users, when viewed holistically, the findings of this study in conjunction with the stakeholder feedback received, indicate deep-rooted, structural flaws in the way that the introduction of technology is approached by the international maritime industry.

## IMPLEMENTATION AND IMPROVEMENT

A major theme that emerged from some stakeholder feedback supported that, although ECDIS has been in development for about 25 years, it was still seemingly in an 'implementation' phase' – a phase in which the maritime industry, particularly the IMO, has very few mechanisms to collect and act upon user feedback to improve the functionality of this critical system. The governance in place, particularly the committee and sub-committee system on which the introduction and the continuous improvement in the maritime industry depends, are too bureaucratic and the meetings too infrequent for the task.

On the other hand, manufacturers have continued to expand the technical standards, and the IHO's revision of the ENC presentation library has helped to reduce the number of alarms to some degree. However, overall improvements to the systems' usability have not been fully realised. Consequently, many of the problems initiated by the combination of some specific requirements of the ECDIS performance standard, the absence of bathymetric fidelity, and a lack of human centred design persist. Such problems include alarm fatigue, too small a screen size, the inability to effectively separate safe from unsafe water, difficulty in undertaking residual manual tasks (e.g. writing notes), and many ECDIS-fitted ships still having to carry and use paper charts.

In view of the potential relatively rapid changes in the technologies and standards available for use in navigation introduced by manufacturers and the IHO, navigation equipment and practices per se are likely to remain transitional i.e. undergoing constant change. In the dynamic environment resulting from digital transformation and the continuing integration of information 'layers', it is imperative that 'user feedback' and the impact of technology on practice is quickly acknowledged and acted upon. This requires agility and would require the IMO to restructure its processes for introducing and continuously improving navigation-related technologies to ensure that:

- **The principals of human centred design are followed.**
- **Mechanisms are in place to enable user experience and feedback to quickly influence technological change and recognised navigational practices.**
- **Performance standards are goal-based rather than prescriptive to enable continuous development, to enable systems to meet different contexts of use, and to avoid difficulties associated with mandatory features.**

# TRAINING

The study's findings and stakeholder feedback also indicate that the navigation training requirements and arrangements for ECDIS had remained 'transitional' i.e. the move from paper charts to ECDIS. The 5-day ECDIS model course remains extant despite it being likely that nearly all the navigators who were trained solely on paper charts and had to complete the ECDIS training have already done so, and most of maritime colleges continue to teach navigation with paper charts. Although college courses incorporate the model course syllabus and provide simulator time in their syllabi, the simulator time is typically spread out over time and limited due to cost. Consequently, cadets often start their sea time with little or no ECDIS knowledge and newly qualified navigators are frequently ill-prepared and must cope with the difficulties associated with ECDIS without really knowing how the systems works. The sparseness of simulation time also results in them also having little experience in managing the different navigational layers (radar, AIS, ENC etc) in integrated systems, or managing navigation alarms.

Most commercial vessels today are navigated using ECDIS or some form of electronic chart and plotter in conjunction with satellite derived positioning due to the advantage and contribution to safety derived from continuous position plotting in real time. In tandem, the use of paper charts has diminished, making its recent naming as the 'standard navigation chart' a misnomer. With the proliferation of ECDIS, the ENC is now the standard, but this is not yet accurately reflected in the STCW or the Voyage Planning Guidelines on which navigation training and practice are based, or in the training available.

This transitional state, in which neither training nor the guidelines for practice requirements accurately reflect the realities of ENC and ECDIS use at sea is anachronistic. It contributes to the knowledge and functionality gaps identified in this study, it does not recognise the new challenges encountered when voyage planning, monitoring and updating charts in ECDIS, and it encourages the teaching of conflicting navigational strategies (ENC and paper charts) in the maritime colleges. That several large ship operators undertake their own bridge simulator training underlines the lack of trust and value in the current training arrangements. The 5-day model course and familiarisation 'on the go' is far from sufficient when operating critical safety equipment.

To enable training to keep pace with 'real-world' practices in today's era of digital transformation in which ENCs are dominant and paper chart use is in decline, several key actions will be required. These include:

- **Ensuring that the focus of core navigation training is taught using ENCs and that a Model Course is available for the teaching of paper chart navigation.**
- **Encouraging flag states, maritime colleges and ECDIS manufacturers to work together to develop and provide technologies that will increase the simulation time available and enable students to complete ENC related assignments remotely.**
- **The revision of the layout and requirements of the maritime Conventions and navigational guidelines to reflect the predominant use of electronic charts and other digitised data, and the increasing importance of managing the different navigational layers in an INS (including the advantages and disadvantages of using radar overlay to verify position).**

# DESIGN AND PERFORMANCE

The lessons learned through this report and how the industry reacts to address these issues will certainly have an impact on how the maritime industry moves into the future, where increased automation, AI and decision support systems will be inevitable.

Although stakeholders were unanimous in the view that the ECDIS was a contributor to safe navigation, several expressed that ECDIS design be improved to make the system easier to use, reduce the number of alarms and enable better customisation for specific navigational contexts. In this respect, the incorporation of human-centred design and human experience will be of significant benefit. Stakeholder suggestions for improvement included making the system 'smarter' by utilising algorithms and real time tidal data, the provision of better interfaces to make residual manual tasks easier (e.g. the e-pelorus for taking and plotting visual LOPs, and bigger screens), rapid and easy access to all key system settings (system status) similar to a conning display, and more standardization of displays and functions.

It was also expressed that ECDIS suffers from being a compromise between being what a paper chart looks like and what could be displayed to meet user needs and the demands of differing contexts if all available data is utilised. For example, depth contours on paper charts are the construct of the cartographer and it is often the lack of contour density on the ENC that makes the ECDIS 'safety contour' inaccurate in separating the safe from the unsafe water. However, far more depth data is usually held by the hydrographers and other organizations than is displayed on nautical charts.

Although the lack of bathymetric fidelity in some areas of the world will persist for many years, high-definition bathymetry data is due to be made available for many geographical areas through S-102 (the IHO's Bathymetric Surface Product Specification). The use of this (gridded) data in ECDIS would allow future ECDIS to generate a far better depiction of the best estimate of safe and unsafe waters, based on the required user inputs (and potentially CATZOCs). In effect, the system would draw its own safety contour rather than be limited to the depth contours currently included in ENCs.

However, to allow this high-definition bathymetry to be used and adjusted in ECDIS to incorporate the height of tide will require amendment to the current hydrographic and performance standards. It will also require mechanisms to ensure that ECDIS and its users are not overwhelmed by large amounts of unnecessary data. Therefore, the benefits of the use of high-definition bathymetry data would bring to ECDIS performance can only be realised if the IMO, the IHO, and ECDIS manufacturers:

- **Work together to facilitate the accurate and automatic separation of safe from unsafe water in ECDIS, balancing the benefits of high-definition bathymetry against the drawbacks of enormous data sets.**

## ACTIONS AND POTENTIAL ACTIONS WITH RESPECT TO ENCS

During 2021, IHO's Worldwide ENC Database Working Group (WENDWG) developed a questionnaire intended for ENC producers to report their production plans of HD ENCs, noting the increasing importance of understanding global plans regarding HD ENC production. The WENDWG questionnaire has several general objectives, including:

- To gather IHO Member States' intentions on the production plans of HD ENCs in their areas of responsibilities (national level, or as primary charting authority).
- To collate the production techniques, timeliness dataflow and arrangements with port authorities.
- To identify challenges faced by the current and prospective HD ENC producers namely, production and distribution chain, quality control and consistency with other nautical products (ENCs, ENC coverage, nautical publications, etc).
- To share harmonization/best practices insights and know-how.
- To interview HD ENCs Producers on their intentions once S-102 becomes operational.

The questionnaire was distributed to IHO member states in July 2021 and the survey report is planned to be finalised in February 2022, with conclusions and recommendations to be reported to the IHOs Inter-Regional Co-ordination Committee later that year.

In addition, feedback from the WENDWG on the ECDIS safety study suggested potential avenues to pursue to improve the coverage of HD ENCs. The feedback also offered potential ways of addressing other ENC issues such as updating (T&P equivalents and file sizes), the encoding of point features, the number of alerts in pilotage areas, the population of depth data over seabed obstructions, cell transitioning, and cells that are not in the WGS84 datum. Such feedback strongly indicates that there is much that can and should be done.

## NEXT STEPS

The findings of this study identify many of the problems ECDIS users experience with the system at sea today, and in the short-term it is the ambition of the DMAIB and MAIB to engage with ECDIS stakeholders to try to effect the changes required to improve ECDIS performance through better bathymetry along with changes in design and training. However, the findings also point towards deep-rooted, structural flaws in the way that new navigation technologies are implemented. Flaws that continue to hinder system development and the evolution of new ways of working, and which also promote reactive rather than proactive approaches in many areas.

Addressing such key issues will challenge traditional thinking and structures. It will also require international liaison and agreement. Consequently, no recommendations have been made but it is hoped the study will serve as a prompt and be used by the maritime industry as a catalyst for change.

# APPENDICES

# TABLE 1: Groundings in which ECDIS configuration and utilisation was contributory

| VESSEL/REPORT | CONTRIBUTING FACTOR | | | | |
|---|---|---|---|---|---|
| | Chart Reliability and Presentation | Route Planning/ Execution | Route Monitoring | System/Interface | System Knowledge |
| **CFL Performer**<br>Date: 12 May 2008<br>Location: Haisborough Sand, UK<br>ECDIS: Furuno FEA2107<br>MAIB report 21/2008 | | • Amended route planned over chart-ed shallows<br>• Visual check only cursory<br>• Route not cross-checked by master<br>• Auto route check not used | | | |
| **CSL Thames**<br>Date: 9 Aug 2011<br>Location: Sound of Mull, Scotland, UK<br>ECDIS: Telko Tecdis 4.6.0<br>MAIB report 2/2012W | | | • OOW altered towards shoal water to avoid an-other vessel<br>• ECDIS not monitored<br>• Audible alarm disabled<br>• Safety Contour not appro-priate for vessel's draught | | • OOW had limited ECDIS knowledge |
| **Dart**<br>Date:1 Aug 2013<br>Location: Aafjorden, Norway<br>ECDIS – Not Known<br>DMAIB report Jan 2014 (Case 2013013831) | | | • Audible alarm not working<br>• Vessel deviated from the planned route after the OOW fell asleep | | |
| **Ovit**<br>Date: 18 Sep 2013<br>Location: Varne Bank, English Channel<br>ECDIS – Maris ECDIS900<br>MAIB report 24/2013 | | • Route planned over charted bank<br>• Route planned by inexperienced officer<br>• Route not checked by master | • Route monitored solely against the intended track<br>• 'Overscale' display<br>• Safety settings inappro-priate<br>• Audible alarm not working | | • Officers unable to effectively use ECDIS |
| **Commodore Clipper**<br>Date: 14 July 2014<br>Location: Little Russel, Guernsey<br>ECDIS: Transas Navi-sailor 4000<br>MAIB report 18/2015 | | | • ECDIS not utilised effec-tively<br>• Inappropriate safety contour<br>• XTD alarm ignored<br>• Audible alarm disabled | | |

| VESSEL/REPORT | CONTRIBUTING FACTOR | | | | |
|---|---|---|---|---|---|
| | Chart Reliability and Presentation | Route Planning/ Execution | Route Monitoring | System/Interface | System Knowledge |
| **Nova Cura**<br>Date: 20 Apr 2016<br>Location: Mytilini Strait, Greece<br>ECDIS: SAM Chartpilot 9330<br>DSB report 'Digital navigation: old skills in new technology Lessons from the grounding of the Nova' - 2017 | • Position of reef inaccurately charted on Greece ENC<br>• Differences between Greece and Turkey ENCs at cell border | • Master and navigator assessed that CATZOC for area was 'U' | | • Modernity of ECDIS obscured that the system relied on ENCs with low level of reliability<br>• ENC presentation fosters assumption that the information is up to date | |
| **Molly Manx**<br>Date: 19 Aug 2016<br>Location: Otago, New Zealand<br>ECDIS – JRC JAN701B<br>(TAIC investigation MO-2016-204) | | • The XTD was wider than the navigable channel | • Bridge team/Pilot did not notice that vessel had deviated from the planned track<br>• Safety settings not IAW onboard instructions<br>• ECDIS was not configured for navigation in a narrow channel, which meant the crew were not adequately monitoring the progress of the vessel in support of the pilot, who was mainly navigating by visual references | | |
| **Vasco de Gama**<br>Date: 22 Aug 2016<br>Location: Southampton, UK<br>ECDIS: SAM Nacos Platinum<br>MAIB report 23/2017 | | • A planned turn around a charted bank was not achievable in the conditions experienced | • Bridge team unable to monitor vessel's progress/pilot's actions<br>• Safety parameters not set | • Display not optimised | |

| VESSEL/REPORT | CONTRIBUTING FACTOR | | | | |
|---|---|---|---|---|---|
| | Chart Reliability and Presentation | Route Planning /Execution | Route Monitoring | System/Interface | System Knowledge |
| **Muros**<br>Type: Bulk Carrier<br>Date: 3 Dec 2016<br>Location: Haisborough Sand, UK<br>ECDIS: Maris ECDIS 900<br>MAIB report 22/2017 | | • Revised route planned over shallows<br>• Visual check conducted at small scale<br>• Alerts generated by the ECDIS automatic route check ignored | • Audible alarm disabled<br>• OOW performance potentially affected by low state of arousal | | |
| **L'Austral**<br>Type: Passenger Ship<br>Date: 9 Jan 2017<br>Location: Snares Island, New Zealand<br>ECDIS: Sperry Marine VisionMaster FT<br>TAIC report MO-2017-201 | • ENC used was not an official chart | • CATZOC for area was 'U' | • Position was not being monitored during boat operations | | • Crew not familiar with the ECDIS limitations (ENC reliability, safety parameters and alarms) |
| **Umm Salal**<br>Type: Container Ship<br>Date: 6 Apr 2017<br>Location: One Fathom Bank, Selangor, Malaysia<br>ECDIS: Sperry Marine VisionMaster FT<br>MSIU report 7/2018 | | | • ECDIS display not monitored due to OOW focus on shipping<br>• OOW briefly left the bridge to go to the chart room<br>• Audible alarms had been switched off to avoid continuous activation | | |
| **Universal Durban**<br>Type: Bulk Carrier<br>Date: 13 May 2017<br>Location: Pulau Serasan, Indonesia<br>ECDIS: Furuno FEA2107<br>MSIU report 10/2018 | • Large scale ENC for area inadvertently deleted<br>• Small scale 'general' chart used<br>• The quality of ENC data was not within the threshold of the promulgated CATZOC | • Planned route deviated from the designated archipelagic sea lanes and Admiralty Sailing Directions were not used<br>• The visual check of the route was cursory<br>• The route was not checked by the master | | • The system auto route check did not identify the navigational danger within the XTD | |

| VESSEL/REPORT | CONTRIBUTING FACTOR | | | | |
|---|---|---|---|---|---|
| | Chart Reliability and Presentation | Route Planning/ Execution | Route Monitoring | System/Interface | System Knowledge |
| **Freyja**<br>Type: Chemical Tanker<br>Date: 28 June 2017<br>Location: Svartevatnet, Norway<br>ECDIS: Maris ECDIS900<br>MSIU report 13/2018 | | | • Vessel's deviation from planned route was not detected<br>• Audible alarm was either not set or did not activate | | |
| **Kea Trader**<br>Type: Container Ship<br>Date: 12 July 2017<br>Location: Recif Durand, Pacific Ocean<br>ECDIS: JRC JAN901B<br>MSIU report 14/2018 | | | • The route was monitored on an overscale ENC<br>• A caution message related to the ENC datum was overlooked | | |
| **ABFC Roebuck**<br>Type: Border Force Cutter<br>Date: 30 Sep 2017<br>Location: Henry Reef, Queensland, Australia<br>ECDIS: Sperry Marine VisionMaster FT<br>ATSB report 335-MO-2017-009 | • The use of point feature objects to represent physical features of relatively significant spatial extent on an ENC can increase the risk of the hazard posed by such features being misinterpreted by mariners and potentially reduce the effectiveness of the ECDIS safety checking functions | • Revised route planned over a charted reef<br>• The effectiveness of the visual check was likely influenced by a misinterpretation of chart symbology and possible obscuration of the reef's chart symbol and label | • The ECDIS audible alert buzzer was permanently muted.<br>• Onboard instructions contained no guidance on the adjustment of safety settings to suit the changing navigational environment | • It was likely that the look-ahead did not encounter the isolated danger symbol marking the reef and therefore did not generate an alarm<br>• The ECDIS was fitted with non-commercial software that was not type approved | • The navigator misunderstood the system route check function and expected that the ECDIS would not save a route plotted over a charted danger<br>• The deck officers did not have an adequate level of knowledge to operate the ECDIS as the primary means of navigation<br>• The training undertaken by the deck officers was not effective in preparing them for the operational use of the ECDIS |

# TABLE 2: List of figures presented in the safety study

| Figure | Title | Credit | Comments |
|---|---|---|---|
| 1 | Bridge layout on a modern ship | MAIB | Taken during onboard research |
| 2 | Bridge layout on a cargo ship | MAIB | Taken during onboard research |
| 3 | CATZOC Table | UKHO | https://www.admiralty.co.uk/AdmiraltyDownloadMedia/Blog/CATZOC%20Table.pdf |
| 4 | CATZOC as displayed by ECDIS | DMAIB | Taken during ECDIS simulation |
| 5 | Isolated Danger Symbol | DMAIB | Taken during ECDIS simulation |
| 6 | Track planned over safety contour | MAIB | Taken during onboard research |
| 7 | Absence of danger lines or no-go areas | MAIB | Taken during onboard research |
| 8 | Indication triggered by the Look Ahead | MAIB | Taken during onboard research |
| 9 | Simple text annotations | MAIB | Taken during onboard research |
| 10 | Ship within buoyed channel | MAIB | Taken during onboard research |
| 11 | Track without XTD | MAIB | Taken during onboard research |
| 12 | Track without XTD in pilotage waters | MAIB | Taken during onboard research |
| 13 | Ship outside the narrow XTD | MAIB | Taken during onboard research |
| 14 | Route Check page on ECDIS | MAIB | MAIB Report 24/2014 “OVIT”:<br>Figure 11 – MARIS 900 Route Check Page |
| 15 | Overscale Pattern (Jail Bars) indicating over expanded chart | DMAIB | Taken during ECDIS simulation |
| 16 | Vessel outline + predictor | MAIB | Taken during onboard research |
| 17 | Vessel outline + predictor | MAIB | Taken during onboard research |
| 18 | Radar image overlay/chart underlay | MAIB | Chart Underlay |
| 19 | AIS overlaid on ECDIS display | MAIB | Taken during onboard research |

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