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Human-Centred Design in Modern ECDIS Systems

Bachelor's thesis in Nautical Science
Supervisor: Bjarne Pareliussen
May 2024

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Sammendrag

Hensikten til rapporten er å etterforske hvor effektivt brukergrensesnittet, og generelt sett systemdesignet, av 'electronic chart display and information system' (ECDIS) er i å bistå sine brukere med systembruk. Opphavet til rapporten er begrunnet i en rekke ulykkes rapporter der ECDIS var en vesentlig grunn til ulykken. Ettersom systemet er såpass viktig om bord så er rapporten tenkt både viktig og relevant til næringen. En rekke datainnsamlingsmetoder var brukt for å svare på denne problemstillinga. Rapporten fant at noen viktige deler av systemdesignet til ECDIS var blant de hovedårsakene til flere ulykker. I tillegg så viste det seg at data samlet gjennom et eksperiment pekte på at forskjellig systemdesign mellom ulike system førte til store forskjeller i brukbarhet mellom ellers like grupper. Rapporten også fant at de systemene som var etterforsket i rapporten la ikke nok vekt på visse aspekter sånn som ergonomien, menneskelig-orientering, og brukbarhet. Dette fører da til en økt risiko til sjøs. Rapporten anbefaler dermed at mer vekt bør legges på sånne aspekter av utstyret og at mer akademisk etterforskning er gjort i dette området.

Summary

This paper's aim is to investigate how effective the user-interface and overall system design of modern electronic chart display and information systems (ECDIS) is in assisting the user with system operation. This is grounded in a number of accident reports where ECDIS played a significant contributing role. Since the system is so crucial onboard, the paper is thought to be relevant and important to the industry. Several data-collection methods were employed to answer this research question. The study found that key features of ECDIS design were contributing factors to a number of maritime accidents. In addition, the data collected from an experiment confirmed that different system designs lead to significant differences in usability between a homogenous group of users. The study also found that the systems that were investigated in this report do not put enough focus on human-centred, ergonomic design, and usability. This in turn increases the risks to safety at sea. The paper's findings recommend for more weight to be put into this aspect of the equipment, as well as more research to be done on the topic of usability and human-centred user-interfaces in the maritime industry.

Acronym

ECDIS	Electronic Chart Display and Information System
NTNU	Norges Teknisk-Naturvitenskapelige Universitetet
IMO	International Maritime Organisation
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
IT	Information Technology
UI	User-Interface
UX	User-Experience
MAIB	Marine Accident Investigation Branch
DMAIB	Danish Marine Accident Investigation Board
GNSS	Global Navigation Satellite System
SA	Situational Awareness
ENC	Electronic Nautical Charts
ULCC	Ultra Large Crude Carrier
TLX	Task Load Index
MWL	Mental Workload
C/O	Chief Officer
2/O	Second Officer
3/O	Third Officer
LNG	Liquified Natural Gas
CATZOC	Categories of Zone Of Confidence

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1 Introduction

This paper stems from the author's experience of learning and using The Electronic Chart Display and Information System (ECDIS) system as part of a Bachelor of Nautical Science degree at Norges Teknisk-Naturvitenskapelige Universitetet (NTNU) in Ålesund.

ECDIS is a staple of modern-day maritime navigation. Alongside radar, ECDIS is the primary system used by navigators to plan a ship's route and maintain a continuous awareness of the ship's geographical position. The system is a replacement to paper charts used prior to 1990s (Simrad, 2024), although it incorporates many features previously unavailable on paper charts. Nonetheless, the primary functions of the ECDIS are simple – to be able to plot and monitor a route, as well as any other functions available to paper charts (such as taking a bearing) (Maritime Safety Committee, 1995). Yet it is the experience of many, that the system design is outdated, complicated, unaccommodating to users, and simply unintuitive.

Following the grounding of the Nova Cura in April of 2016, a general cargo ship, on the shoals of the Lamnas Reef, The Dutch Safety Board conducted an investigation into the accident, and alongside several things, they concluded that the root cause of the incident lay partially in the design of the ECDIS (The Nautical Institute, 2017). It was concluded that the ECDIS system offers up too much information which cannot adequately be processed by the navigator, that the retrieval of information is unintuitive, and that these issues should be taken into consideration in the future development of ECDIS.

1.1 Research Question ("Problemstilling")

This paper seeks to provide empirical evidence that will hopefully be useful to the manufacturers and regulatory bodies of ECDIS software. The paper shall endeavour to dig deeper into the findings of the Nova Cura by comparing the incident to a number of similar incidents that have occurred over the recent past. This will be supplemented by quantitative numerical data collected as part of an experiment. As ECDIS is such a central part of modern navigation, its thought that this topic is both worthwhile and relevant to the industry.

In simpler words, it can be said that this paper takes it upon itself to evaluate "*To what extent is the user-interface of ECDIS systems effective in aiding the operator?*"

The paper shall evaluate, analyze, and discuss the various aspects of the system in regard to modern understandings of user-interface (UI) and system design, as well as undertake the collection of quantitative data (in the form of an experiment) to aid the discussion and answer the abovementioned research question.

1.2 Limitations

Due to the nature of the paper, the study will unfortunately be limited in scope, as well as in a number of practicalities. A plethora of data-collection means can be utilized by this paper, such as interviews with mariners, focus groups consisting of deck officers, and experiments specifically designed to evaluate UI in systems. However, due to the lack of time and funds, the scope of the paper will be limited to evaluating only a number of publicly available cases and an experimental group consisting of students. Perhaps the largest limiting factor in this paper, that will inevitably affect the validity and reliability of the results, is the subpar sample size available for the experiment. In addition, further methods of collecting data cannot be utilized to supplement the small sample size.

The experiment itself is limited to assessing only two different ECDIS system types. This is due to the systems available for the study. The number of people to run and control the experiment is also severely limited to the size of one person – the author.

In addition, it must be mentioned that the author himself is unfortunately not trained, nor professionally experienced in the matter of academical writing. This is a factor that unfortunately, and for obvious reasons, cannot be changed in the time available.

2 Background

2.1 Context

2.1.1 History of ECDIS

ECDIS is a geographical information system used for nautical navigation as an alternative to traditional paper charts (Simrad, 2024). ECDIS became a valid alternative to paper charts as recently as the year 2000 when The International Maritime Organisation (IMO) revised The International Convention for Safety of Life at Sea (SOLAS) regulation V/19. However, ECDIS was in use even before then, but it was not legally considered a valid alternative to paper charts, and so it was only used as a supplementary aid by navigators. Recognizing the advantages of ECDIS, in 2009 IMO adopted further amendments to regulation V/19 to make the carriage of ECDIS mandatory. The amendment entered into force in 2011, which began the process of both fitting new ships with ECDIS and phasing-in ECDIS on older ships (International Maritime Organisation, 2019).

It must be noted however, that there is no one make or model of ECDIS that is used as the standard. ECDIS is the umbrella term encompassing many different manufacturer-specific systems that all serve the same purpose. The manufacture of ECDIS systems is governed by performance standards set out by IMO in resolution MSC.232(82) and A.817(19). The system must fulfill one of these performance standards, depending on the date of its installation (International Hydrographic Organization, 2022). As a result of the performance standards leaving a lot of ‘breathing room’ for the manufacturers, there is considerable variation in design and functionality between different systems. Because of such large variance between systems, the convention for Standards of Training, Certification, and Watchkeeping (STCW) has been amended, and after January 1st 2017, all masters and officers serving on ships fitted with ECDIS are required to undergo both general training and type-specific training (Safety4Sea, 2018). As of February 2024, there were at least 14 different manufacturers of the system (NauticExpo, 2024).

2.1.2 What is System Design & User-Interface?

The traditional definition of system design within the Information-Technology (IT) Industry is the process of designing the architecture, interfaces, and data for a system that satisfies specific requirements (Schaffer, 2024). In the context of this paper however, the definition is narrowed to only the parts of the software that the user interacts with or sees. So aspects of system design such as architecture, back-end development, data storage, etcetera, are not addressed.

In conjunction with system design, user-interface is traditionally defined as the point of human-computer interaction and communication in a software (Churchville, 2021). It is the point at which humans can communicate with systems. For the scope of this paper, this is an accurate definition. In tandem with UI, user-experience (UX) is also important to consider. Unlike UI, UX covers the *entire spectrum* of user experience, including things such as the design of the actual device, the context in which the device is used (in a work office, or on board a ship in a storm?). UI is one of the constituents that makes up UX (Interaction Design Foundation, 2024).

So while within the context of this paper system design and UI are very similar, the key difference between the two concepts is that system design is a big-picture approach that views every aspect of the system and considers it in terms of the overall design and intention behind that design. On the other hand, user interface is only the end-product of that system design – only what is on the screen for the user to interact with.

2.2 Why is System Design Important?

Following an increase in the number of groundings and accidents, UK, and Danish maritime authorities (MAIB and DMAIB, respectively) have recently published a report on the application and usability of ECDIS from the practitioner's perspective (Marine Accident Investigation Branch & Danish Marine Accident Investigation Board, 2021). In this investigation, a number of deficits were found with the way ECDIS systems have been implemented in modern navigation and it was found that, among other things, the system design can be significantly improved. Among the conclusions, the report states that while ECDIS does contribute to safe navigation, the challenges that have accompanied its introduction are problematic, such as ‘human-centered design not being considered’. Several stakeholders expressed that the system should be made easier to use in the future. This concern over the lack of human-centered design is mirrored by many academics, as well as navigators.

In his paper on coastal navigation in a digital era, Odd Sveinung Hareide, PhD in Maritime Education and a Masters in Technological Leadership (LinkedIn, 2024), points out the subtly changing metrics and goals of a good navigator. In the past, the primary goal of a navigator was to find and fix the position of the ship, but in recent times this task is done automatically by Global Navigation Satellite Systems (GNSS). As a result, the responsibility of the navigator has shifted to monitoring the vessel’s position, as opposed to finding it. Unfortunately, research shows that people are not very good at monitoring systems naturally and the quality of a person’s visual monitoring degrades after only 30 minutes (Hareide, 2020). It is for this reason that Hareide proposes not only standard operating procedures, but a “human-centered design of interfaces to support the navigator in the decision-making process”. Because a problem with the human mind will not be overcome through training, but through systemic design changes to the systems that humans monitor.

Hareide’s point is mirrored and supported within his article by the work of Christopher D. Wickens (Wickens, 2002) who identifies 3 components of Situational Awareness (SA); these being Spatial Awareness, Task Awareness, and System Awareness. An overview of these can be found in Figure 1 below.

Figure 1: Breakdown of Situational Awareness, (Hareide, 2020)

What is deemed relevant for this discussion is the role of system awareness in SA. According to Wickens, system awareness is the awareness of the processes that happen within automated systems. In this case, that would be the ECDIS system. But as Wickens points out, it becomes difficult to maintain system awareness with complicated automated systems with poorly designed symbolic displays. In this, he describes the need for an ergonomic system design, to help support the SA of a navigator. System awareness constitutes a large part of the navigator's situational awareness, so it must follow that the system must be designed in a way that is most easily understood and monitored. In such a way, the operator's awareness of the system will be increased, something that will perhaps be of benefit in a different yet related area – namely that of over-reliance by navigators on the system.

It is well known that the use of ECDIS has led to an over-reliance on the system by the navigator. In fact, the term "ECDIS-assisted grounding" has even been coined (Thompson & Grey, 2017). This can be attributed, in a large part, to the system's design. When the aforementioned Nova Cura grounding happened in April of 2016, the investigation into the incident revealed unreliable Electronic Navigational Charts (ENC) being one of the root causes of the incident (The Nautical Institute, 2017). The ECDIS system contains many advanced functions and evaluating the reliability of ENC data is not an obvious or an easy process. The modernity of the system gives off the impression to operators that the sailing charts are of the same quality, which leads to over-reliance on the system's data. Ideally, the system should focus on highlighting its own limitations to give navigators a deeper, more nuanced understanding of the data upon which they make decisions.

The modern and most widely accepted perspective on these issues associated with the newly emerged ECDIS technology, is to put the responsibility, and the need for improvement, on the navigator. There exist many papers written on the navigational safety of ECDIS urging navigators to "Avoid over-reliance on ECDIS" (Safety4Sea, 2015). While this is a fair stance to take, and certainly the human element can do nothing but improve because of extra training, it is equally important to hold the digitalized systems and their manufacturers up to the same standards. A number of issues exist associated with the use of ECDIS, and in general with digitized navigational systems, and these must be targeted by the systems that cause them. The Norwegian marine insurance company "Skuld" advises the marine industry that while the most common cause of failure is simply written off as 'human error', it is worth taking a look at safety investigations in the airline industry, where such a root cause would be investigated further. The airline industry realized long ago that a single error such as that may be caused by many different contributing factors, such as the design of the systems in use by the operator (Laursen, 2016). This is concurrent in the views of Sidney Dekker, a professor at Griffith University in Australia, known for his work on human factors and system safety (Griffith University, 2024). According to Dekker, human error is a consequence of deeper issues with the system, such as bad design, poor training, mental overload, and so on (Dekker, 2005). In an article about the liabilities of ECDIS, Martyn Wingrove, a long-time marine journalist and editor at “Riviera”, writes that “Despite wide use of generic and type-specific training, misuse of ECDIS still widely occurs, and increasingly port state control inspectors are finding issues with ECDIS and ENC set up” (Wingrove, 2016). As can be gleamed from the passage above, training alone is an inefficient way to address the aforementioned issues. An ECDIS system who’s known problem is that the operator relies too much on it, must address this issue through systemic design changes; to reflect this fact, and highlight the vulnerabilities of the system through user interface, in a way that influences the way the operator interacts and views the system. Poor design increases cognitive demands for users, which can lead to incidents in safety-critical contexts (Woods & Patterson, 2000).

The maritime industry has historically been slow to adopt new changes in technology. Without a doubt, this is surely in part because of the heavily regulated nature of the industry and its close link with bureaucratic organizations such as IMO. And bureaucratic organs are widely recognized as being slow to adapt to new situations (Jacobsen & Thorsvik, 2020). So, it is unsurprising that while the rest of the world has taken a huge step forward in ergonomic design, the maritime industry, just like one of its fully-loaded ULCCs, is slow to turn to the new standards.

3 Method

In order to effectively address the research question, a number of different data-collection methods have been employed. It is with the aim of increasing the validity of the results, that a number of different methods have been undertaken. This way the deficiencies in one method might be filled out by the advantages of another method. A broader collection of data will also create a healthier, more reliable dataset and conclusion.

For the purposes of this paper, three data-collection methods have been used. These are a literature study and an experiment; the latter of which is divided into a task section and a survey section (the surveys consist of the task-load-index and the digital survey).

These three methods not only provide a plenitude of data that can be analysed, but also provide data that is both subjective and objective. In this way, the methods all seek to collect data on the way users interact with the UI and overall system design.

3.1 Literature Study

In order to contrast and corroborate data collected from the experiment, in the light of the leading opinions and theories from the industry, a literature study will be undertaken within the "Literature Study" section of this paper. A comprehensive summary of the leading opinions of the industry, related to human-centered UI, will be presented. This will then be compared to case-by-case examples from an ECDIS system, and it will be discussed whether the current design of the ECDIS system follows the "best-practice" guidelines set out by the industry and experts. By doing this, the paper seeks to put ECDIS into context, within the broader standards other industries have adopted. In addition, this will also serve to buffer the data collected from the experiment, which will increase the reliability and validity of the conclusions.

The reason for the literature study being chosen is that it is thought it would be best-suited to answer the research question. There has been a plentitude of accident cases in the recent past that point to ECDIS design flaws being a contributing factor. It is thought that an evaluation of such accidents will provide good real-world data to aid the conclusions of the paper.

3.2 Experiment

An experiment was conducted in connection with this paper to collect data from ECDIS users, specifically regarding the system's UI. Results from this experiment will be presented in the "Experiment Results" section (the fifth) and will then be discussed and contrasted with the literature study in the "Discussion" section (the sixth).

The reason for an experiment being chosen for this paper is that it is thought that the nature of this method, will by its very nature, lend validity and reliability to the conclusions of the paper. As well as contribute greatly to accurately answering the research question. An experiment provides physical real-world data that can be numerically analysed. The use of statistics in the paper goes a long way to buffer the limitations forced upon the study. An experiment will also diversify the range of data that is available for analysis. However, more practical details regarding the experiment will be discussed below.

The experiment consisted of first year bachelor students in their second semester of studies of "Nautikk" at NTNU in Ålesund. The reason behind this group being chosen is that it is thought that they would be able to provide the best and most unbiased feedback as new users. If a group of third year students were used, or alternatively, a group of experienced officers, their opinions and experiences with the system would be skewed by familiarity and time spent training with the system. Such a group would be unable to provide accurate feedback regarding, say, the intuitiveness of a user interface, since they have spent countless hours familiarizing themselves with said system. As such, a group of first year students was used, who have the theoretical background for knowing how to execute tasks related to the system, but not the practical experience with this particular system. It is worth noting that at that point in their studies, they had not yet been introduced to the ECDIS system and have been working purely on paper charts. However, a number of students have had previous working experience with ECDIS onboard, to compensate for this, the students were asked to provide information regarding the number of hours they have spent working with the system prior to their participation in the experiment. This statistic will be provided for the benefit of the reader when the results from the experiment will be presented.

Regarding the actual workings of the experiment – the experiment was run on two different ECDIS systems, so that two different types (both common in the industry) could be compared. These were the T-ECDIS made by Telko (Telko, 2019), and K-ECDIS made by

Kongsberg Maritime (Kongsberg, 2024). The experiment consisted of thirty-seven people in total. Eighteen of them used T-ECDIS, and nineteen of them used K-ECDIS. In order to reduce bias, it was specifically decided that both groups would only use one type of system. As opposed to doing the experiment on both. This because it is thought that the experience gained by completing tasks first on one system, and then on another right afterwards would introduce unnecessary bias to the experiment. So even though the sample size is significantly reduced, the reliability of data obtained is far more reliable.

Nonetheless, the experiment's reliability suffers heavily from such a small sample size. Thus, any conclusions drawn from the experiment should be taken as suggestions to carry out further research, where a greater sample size might be obtained.

The experiment consisted of two documents, a form, and a survey. A form with three tasks, each of them followed by a task-load-index (TLX), and at the very end a 'weightings' form (which is related to the TLX indexes). Afterwards the students were asked to complete a digital survey. Perhaps what is easiest is thinking of the experiment in terms of tasks and surveys, which is how the results will be presented in the "Experiment Results" section.

3.2.1 Tasks

The tasks section contains the participants' personal information (such as age, gender, and experience) and the three tasks the students were asked to perform with the help of ECDIS. Since most of the students had never used these systems before, an approximately 20-minute-long presentation was given on PowerPoint illustrating how to complete all 3 tasks. It is worth noting that in addition to completing the actual task, the students were also asked to record how much time it took them to do so. These tasks were:

- "Bearing Calculation" – The students were given access to an accurate radar picture with no interference and no GNSS signal, and an ECDIS interface which displayed the ship's position, but offset by 600 meters North, and 300 meters West from the "true" position which was accurately displayed on the radar. The students were informed of this 'GPS error' and told to find their true position (in terms of coordinates) in ECDIS using the "Bearing Calculation" function present in both systems. It is worth noting that every student was familiar with the process of taking a bearing. The distance between the position found by the students and the true position is the result from this task. This distance was found using an online tool which utilised the Lambert formula (Calculator.net, 2024).

- "Route Plotting" – The students were asked to complete several sub-tasks which go into planning a route. These were:
  - Plotting a route of 3 waypoints
  - Deleting the middle waypoint
  - Adding a waypoint back to the middle
  - Setting in a parallel index line

  If successful with the tasks, the students were asked to check a checkbox. It is worth noting that a control of these tasks was not undertaken, and hence the data relies on the honesty of the test subjects, which to a degree reduces the reliability of the data.

- "Finding an Unknown Map Symbol" – Lastly, the students were shown a specific symbol on the nautical charts before them on ECDIS, they were then told where to find this symbol and write down what the symbol meant with the help of the system's information menu. Weight was placed on the fact that the information was to be obtained using the system, and that even if the subject knew the meaning of the symbol, they should not write it down unless they found it in the system. This also relies on the honesty of the test subjects, and hence slightly decreases the reliability of the results. The result was noted as either a success or a failure.

3.2.2 Surveys

The surveys section can be split into 2 parts – the TLX and the survey. The TLX was developed by NASA for research purposes, specifically to measure the subjective mental workload (MWL) of a task, or a series of tasks. It rates performance across 6 dimensions to determine an overall workload rating.

The thought is that system design should always facilitate the lowest possible workload rating. Meaning that tasks can be performed as easily as possible. This is especially important in the maritime industry, since so many of the tasks a navigator has to perform dictate the safety of the ship, crew, and environment.

The index consists of a ‘ratings’ form, which follows every task, and a ‘weightings’ form right at the end. The subjects rate their performance on the 6 different scales in the ratings form. The weightings form then presents 15 pair-wise combinations of the categories, and the subject must choose which one was the most important. This procedure accounts for 2 possible sources of between-rater variability: differences in workload definition between the subjects and differences in the sources or workload between the tasks (Digital Healthcare Research, 2024). The overall workload rating for each task is then available after the data is processed.

The second part of the survey section was a simple digital survey conducted after the experiment. The questions were designed to gather numerical data on the subjects’ opinions of the system’s design.

4 Literature Study

To be able to analyse the effectiveness of ECDIS system design, it is crucial to know what constitutes good system design. Hence, in this section of the paper, a multitude of sources will be cited to answer that question. This will then be compared to case-specific incident reports where use/misuse of ECDIS was a significant factor.

According to experts, there are a number of factors that separate the good from the bad, when it comes to UI. Daniel Florido, Chief of Web Development & Designer, the director of Pixelstorm, says that the most important part is “intuitiveness” (Studio, 2024). In the grounding of the “Nova Cura” in April 2016, it was found that ECDIS system design played a meaningful role (The Nautical Institute, 2017). Among the critiques that were put forward by the Dutch Investigation Board, they included that the retrieval of information from the ECDIS system is not entirely intuitive. In addition, and this will become a common theme, they also said that “ECDIS technology is capable of offering much more information than the user is able to process”. In other words, the system is cluttered with information, overloading the operator’s ability to process everything. And while the grounding of the

Nova Cura certainly was not the fault of the software engineers who designed ECDIS, it was a significant enough factor to be included in the conclusions of the investigation.

Cluttering is a big aspect of bad UI design. A software should be as simple as possible, minimalism is key (Studio, 2024). When a ship sails in heavily trafficked, or coastal waters, the navigator must maintain a pristine situational awareness to avoid collision, grounding, or simply incorrect navigation. In such a scenario, a system such as ECDIS should provide the information desired by the navigator in the simplest, cleanest way possible to reduce the cognitive load on the navigator. A cluttered interface is on the other hand, increases the cognitive load, which, as previously discussed, can lead to accidents (Woods & Patterson, 2000). A master of a cruise ship states that ECDIS has numerous design flaws, including cluttering. The system is limited from achieving its potential and is held back by “dinosaur standards”, in terms of resolution, colour, and display in general (MAIB & DMAIB, 2021). In the same report, many users explain how the small screen size that an ECDIS monitor typically uses is not suitable to route surveillance. Small screens where the operator has to strain their eyes to continuously monitor the ship’s course will lead to increased fatigue and inattentiveness. A system should fully accommodate for the users, and it is clear that these systems have not been designed by people who will end up using them – thus integrating otherwise obvious weaknesses such as this.

The joint report by UK and Danish Maritime Investigation Organisations (MAIB & DMAIB) is incredibly useful in understanding the shortcomings and possible improvements to ECDIS systems. The report itself originates from the Maritime Investigation Boards noticing an uptick in the number of incidents involving ECDIS. This led to a joint study being conducted on the way users utilise ECDIS onboard – with the hopes that the information will be used to improve system design and user experience, and thus contribute to safer navigational practices. In the report, it was found that interface and menu complexity increase cognitive workload to the point that its detrimental to the attention the user must give to other systems on the bridge. Going so far as to say that ECDIS requires significant cognitive resources to use its functions, which leads to a minimalist approach by users. In the book “Sensemaking in Safety Critical and Complex Situations: Human Factors and Design” by Stig Ole Johnsen and Thomas Porathe, they explain, among other things, the need for systems to be designed in such a way that reduces the cognitive load on a person as much as possible. This is especially relevant, they point out, in safety-critical and complex situations, such as the navigation of a ship. As such, the ECDIS system does not live up to these standards, as can be seen in the report by MAIB & DMAIB. This is further compounded by further flaws with the system.

Arguably the biggest complaint from operators of ECDIS is the number of alarms the system forces its operators to deal with. This is something also found in the report by MAIB & DMAIB; the distraction of alerts and alarms, especially during pilotage, leads to coping-strategies that very between alarm disablement and normalisation. Alarms played an important role in the grounding of the bulk carrier "Muros" in late 2016, off the coast of England (Sekine, 2021). The incident happened late at night after the 2nd Officer (2/O) amended the carrier's passage plan, according to instructions from the Master, and put the route across a shallow stretch of water called "Haisborough Sand". Upon saving the route, the ECDIS carried out its automatic "check route" function and issued several warnings regarding potentially hazardous points. This window was cleared by the 2/O who did not look at the warnings. This is a perfect example of the aforementioned "alarm normalisation". The audible alarm was also found to be non-operational. This resulted in the grounding of Muros at 02:48am on the morning of the 3rd of December. While it is very easy and perfectly natural to attribute the accident to the inattentiveness and carelessness of the 2/O, it pays off to take a deeper look. In the post-accident examination it was found that when the "check route" function issued a warning regarding the possibly dangerous passage over Haisborough Sand, it was 1 of over 3,000 warnings that were shown on the page. Keeping this in mind, it is unsurprising that some bridge teams develop coping strategies such as alarm normalisation and disablement. In a statement in MAIB & DMAIB's report, a 2/O on a container ship eloquently summarises the issue:

"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" – 2/O, container ship.

In the same section of the report, *eight* officers express the same sentiment regarding the alarms presented by the "route check" function. In the world of safety systems, this phenomenon is known as alarm fatigue (Atlassian, 2024). When operators are presented with an overwhelming number of alarms and alerts, especially when most of these are false alarms, such as in the maritime industry, this can lead to alarms being ignored, missed, or sometimes even disabled. When faced with such a broad and systemic issue, it is not enough to simply instruct operators to "be more attentive". This is a strategy that is doomed to fail because it fights an uphill battle against human nature. Unlike humans however, the systems that serve us are inherently adaptive and should work with, and not against, human nature. The airline industry, yet again, is a leading example of how organisations have fought back against alarm fatigue. In an article, Captain Chesley "Sully" Sullenberger, points out:

"The warnings in cockpits now are prioritized so you don't get alarm fatigue...We work very hard to avoid false positives because false positives are one of the worst things you could do to any warning system. It just makes people tune them out." – Captain Chesley Sullenberger.

In the airline industry, the system may track over 10,000 data points, but the percentage of flights with any alerts, even minor ones, is below 10%. This is a sobering view from the perspective of the maritime industry. A Master onboard a cruise ship explains it like this:

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

In this, the differing perspectives between the maritime and airline industry can be seen clearly. Within the airline industry, false positives are one of the worst things that could happen in warning systems, but in the maritime industry it is commonplace, widely-accepted, and normalised.

A concurrent issue are the manuals provided with ECDIS systems. Both regarding alarms, and general system operation, they fall very far from the mark. In 2001, the then Norwegian Petroleum Directorate, now renamed the Norwegian Offshore Directorate, issued a guideline to design principles in alarm systems (Norwegian Offshore Directorate, 2001). The reason was that the Directorate, through supervisory activities, found unsatisfactory conditions related to alarm systems on petroleum platforms on the Norwegian Continental Shelf, and thus issued a set of guidelines for the design of alarm systems. In this report, the guidelines very clearly state, among other things, that alarms should be well-documented in the documentation (i.e.: manuals), with clear descriptions of the purpose of the alarm. In the report by MAIB & DMAIB, this was not found to be the case. Below is a statement from a 3rd Officer (3/O) of a liquified natural gas (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." – 3/O, LNG tanker.

Even ignoring the guidelines set out by the Directorate, it is certainly obvious to anyone that such a practice is dangerous, ill-considered, and short-sighted, and yet such problems are perpetuated by the inadequate manuals onboard ships.

In addition to the need to properly document the meaning of alarms, the Directorate, in points 37 & 38 advises that alarm information should be informative and easy to understand. The alarm should use terminology or abbreviations that are familiar to the operator. This is to minimise the time needed to understand the meaning of an alarm and avoid misunderstandings. It is a natural, logical rule. An alarm conveys safety information; thus, it should be as easily and quickly understood as possible. Yet the reality that mariners have to deal with finds itself a very long way from the guidelines and common sense set out by the Directorate. In the MAIB & DMAIB report, the Master of a cruise ship reports the following:

"… 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." – Master, cruise ship.

This is a frankly worrying statement. It showcases how ECDIS systems do not follow even basic guidelines laid out more than 20 years ago. It is little wonder that alarm normalisation and fatigue is wide-spread in the maritime industry. The use of abbreviations in such systems is acceptable, if not ideal, when there is plenty of time to look up their meaning. However, onboard a moving cruise ship, navigating in heavy traffic, there simply is not enough time, nor hands to find out what a specific abbreviation means. Which are exactly why points 37 & 38 was included in the report by the Directorate.

Sentiments such as the one expressed by the Master of the cruise ship, are familiar in the maritime industry – namely that the systems in use onboard, are not designed by the people who know how they will be used. An article in the Journal of Navigation, summarises this phenomenon by saying that when engineers develop marine electronic navigation systems, there are many instances where they focus on primarily technical aspects and do not adequately consider the needs and capabilities of the user (Vu, et al., 2019). Consequently, many systems are technologically functional but end up being difficult for users to operate.

A fantastic, practical, example of the flaws that plague modern marine navigation systems, can be found in the grounding of the chemical tanker “Ovit” in the Dover Strait on the 18th of September, 2013. As outlined in the accident report by the Marine Accident Investigation Branch in 2014. In the early hours of the morning, the ship ran aground on the Varne Bank while the Chief Officer (C/O) and a deck cadet were on duty. The ship remained there for 3 hours but was able to refloat on the incoming tide with superficial damage to the ship and no damage to the environment. In the wake of the accident, it was found that user-applied settings, such as the ‘safety contour’, and the ‘cross-track distance’ were not properly set (which will be discussed later at length), the chart size was unsuitable to route-monitoring, and the audible alarm had not been working. However, in addition to these failures, the report also criticizes the software itself on-board the Ovit. An ECDIS called “Maris 900”, manufactured by Simrad (Simrad, 2024). The report explains that *in addition* to the incorrect operation of the ECDIS by the deck officers, a number of features on the Maris 900 system were either difficult to use or appeared not to comply with international standards. Among these critiques were:

- On the check-route page, it is clearly stated that the planned route is unsafe, however the words ‘no alarms’ could also be seen on the same page. Sending mixed signals to the bridge team and increasing the likelihood of misinterpretation. The check-route page can be seen below in Figure 2.

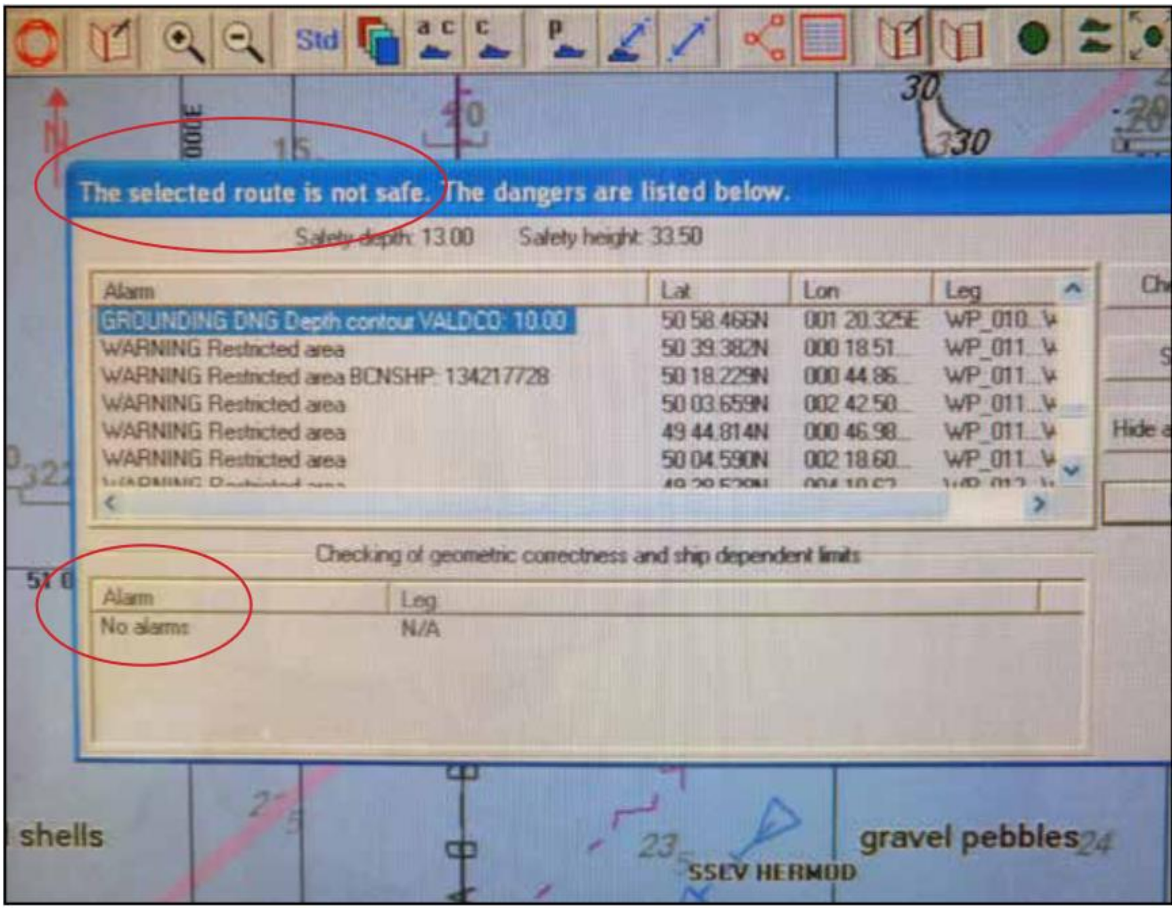


Figure 2: The check-route page in the Maris 900 system.

- Despite its critical importance, the safety contour is one of several "indistinguishable" settings on the same page (see Figure 3 below). The importance of the safety contour is not emphasized to the operator. In this way, the user-interface fails the operator. In the same vein that functions with a higher frequency of use should be prioritized on the interface (Vu, et al., 2019), functions with safety-critical roles should be prioritized above those that are not. As it stands, the system implies, through visual hierarchy, that all 5 settings on the page are equally important.

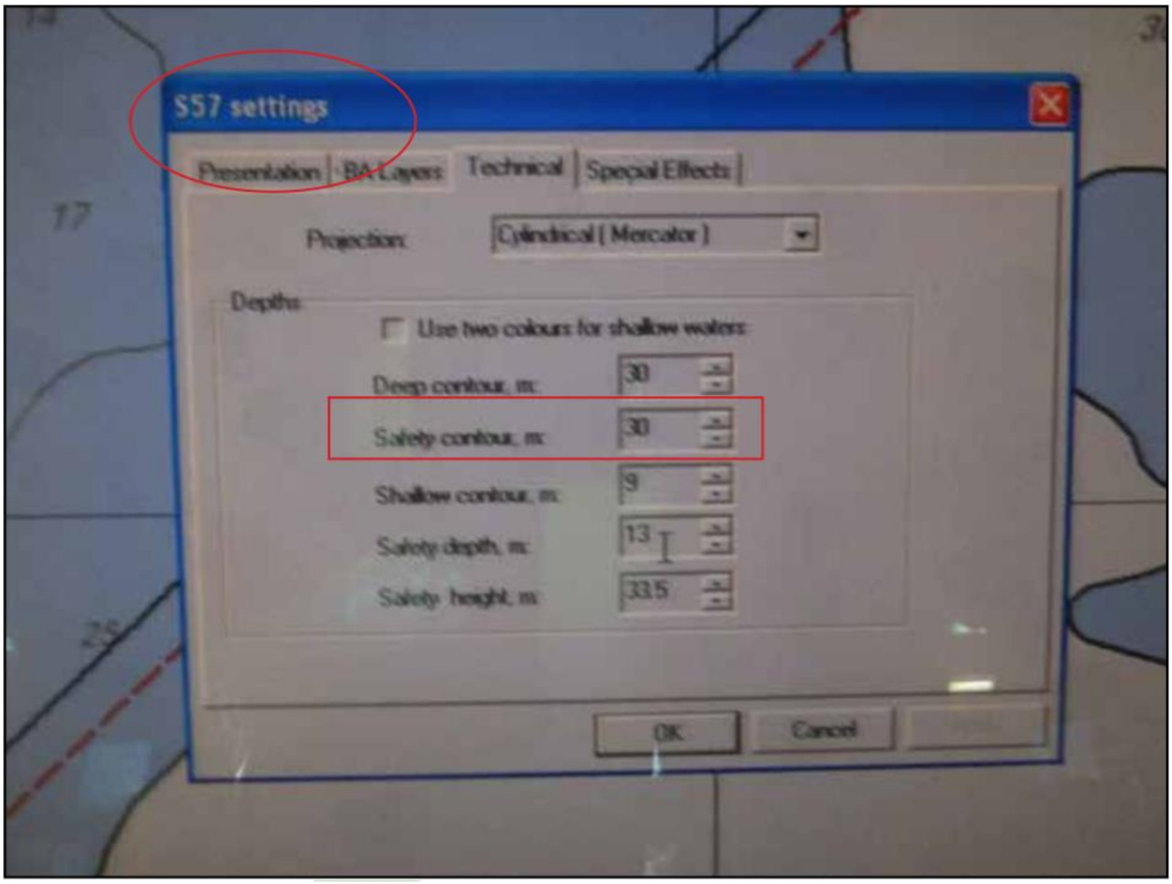


Figure 3: The Maris 900 'S57' input page.

- The alarm that should have gone off because of the safety contour setting, did not. This was found to be because another setting ('display and highlight dangers' option on the guard zone page) was set to 'never', which effectively disabled a mandatory alarm.

- It is a requirement that the vessel's track history be able to be recorded and retrieved, however this could not be done by the investigators after the accident.

So although the brother's share of the blame does indeed lie with the carelessness of the deck officers, the system that is supposed to help and augment their judgement faces serious issues, and potential non-compliance with international regulations and standards. In this, it is easy to see how the user interface of a safety-critical system is both important and how it can be improved.

In the same line of thinking, it is a common trend not unique to the Ovit that safety-critical settings such as the safety contour are used incorrectly. In the grounding of CSL Thames on the Sound of Mull in late 2011, safety-critical settings were found to be set incorrectly, and the audible alarm, once again, was not functional for some time (Marine Accident Invetigation Branch, 2012).

However, a more pertinent flaw is in the ENCs themselves, and the way they and their quality are presented to the operator. Key to understanding this issue is the concept of the "Category Zone of Confidence" (CATZOC), which is a grading given to an ENC charts that ascertains the maximum error that can be expected from the ENC in terms of depth and position (Safety4Sea, 2022). In the MAIB & DMAIB report, it was found that few users pointed to ENCs as a potential source of inaccuracy, as few users understood different zones of confidence in CATZOCs and why these categories could affect the planning and monitoring of a passage. This is a problem since digitized charts (i.e.: ENCs) can give false impressions of their reliability. ENCs are made from the same hydrographic data that paper charts are made with, and are subject to the same sources of error, such as age. However the modernity of ENCs gives them ultimately false impressions of modernity. An ENC made in 1908 would, after being digitized, have all the appearance of a modern chart. In fact, this is exactly what happened during the grounding of the LNG Tanker 'Pazifik' off Indonesia in 2018. The accident report, carried out by the German investigation body 'BSU', "explicitly blamed the accident upon ECDIS, noting that it is 'systemically not yet fully developed" (Nautilus International, 2020). If there was evidence pointing towards the need for improvement of the ECDIS systems, there could be no better quote than the one by the BSU. The ship ran aground a shoal that was not clearly indicated on the ENC. The investigation found that 2 of the Indonesian charts were based on surveys carried out between 1904 and 1908, with the rest of the carts showing significant discrepancies regarding the shoal. The paper chart on which the ENC was based showed the shoal 2 cables from where it actually was. The BSU stated that the biggest shortcoming of the ECDIS is that the CATZOC is not included in the route planning and the associated alarms and warnings. Had the CATZOC been easier to see, it would have been clear that the zone of confidence for the area was 'C'. Meaning a positional accuracy of +/- 500 meters. The report concluded that had the ship been using paper charts, the accident would likely never had happened since the bridge team would have relied on supplementary means of navigation such as sailing directions. In this it can once again be seen how ECDIS systems fail to highlight safety-critical information, such as the CATZOC. As it stands, the system gives an unreasonable impression of modernity regarding the quality of ENC data.

The importance and subsequent ignorance of CATZOC data was also substantial in the grounding of both the Nova Cura, and the passenger ship ‘L’Austral’ off the coast of New Zealand in 2017 (MAIB & DMAIB, 2021). In the grounding of the Nova Cura, the ship grounded on a reef that was charted wrong, and it was found that the modernity of ECDIS obscured the inferior quality of the ENC being used. The crew were unfamiliar with the CATZOC grading and thus could not properly assess the reliability of the ENC they were using. In conjunction, the L’Austral was firstly not using an official chart. In this way, ECDIS robs users of the ability to, at a glance, assess the reliability of a chart, as is possible with paper charts (Dutch Safety Board, 2017). The user-interface can certainly provide more clear input to the user regarding the underlying quality of data.

The issue with ENC reliability is augmented by the design of charts in general. Captain Antonio De Lieto, a PhD candidate at the University of Tasmania, in his paper analysing the factors that led up to the infamous catastrophe of the Costa Concordia, points out several design flaws in vector charts. The Costa Concordia grounded against a rock in the Aegean sea, having attempted a sail-by. In the opinion of Lieto, one of the factors that might have contributed to ‘obscuring’ the rock from the navigators is the lacklustre translation of paper to vector charts. He goes on to compare cartography in paper charts and digital vector charts and describes the issue by saying that:

“it appears evident that the art of cartography got lost in translation from paper to vector charts” – Cap. Antonio De Lieto

The way ECDIS presents chart information to the user, according to Lieto, can be thought of as lacking.

Another issue with navigational systems onboard (such as ECDIS) is the lack of standardization and a common design language between manufacturers (Vu, et al., 2019). Products from different companies often vary significantly in design principles. Analogously this can be compared to the differences between Windows and Mac operating systems (Johnsen & Porathe, 2021). And at the time of the grounding of the Ovit, there were over 30 manufacturers of ECDIS equipment (Marine Accident Investigation Branch, 2014). This presents serious challenges to seafarers who frequently shift vessels, and special danger to pilots who might steer several different ships through challenging waters in the span of a single day. The lack of a single design language significantly increases the cognitive load on the operator. The benefits of a common set of design principles are yet to be utilised by the maritime industry, in the words of Johnsen & Porathe. Benefits such as ease of learning, increased usability, and critically – reduced errors. In their book, they introduce the OpenBridge initiative, whose purpose is to increase the usability of user interfaces in maritime workplaces through collaboration between system developers and by providing shared design principles & guidelines. In this way, the book argues that design consistency can improve sensemaking onboard. In the book, the design principles are applied to designing an ECDIS interface with better usability, and the reader is encouraged to read the report for specifics. Thusly, it is clear that ECDIS can do nothing but improve from increasing standardization across systems.

In the report by MAIB & DMAIB, the ultimate conclusion is that while the study identified an overall positivity towards ECDIS, the problems that were also identified suggest that ECDIS design and use has yet to achieve its full potential. In conjunction, by virtue of its existence, the OpenBridge initiative is itself evidence of a need within the industry to improve usability in ECDIS user-interface, as is supported by the multitude of sources outlined in this section of the paper.

5 Experiment Results

This section will present the results of the experiment carried out to investigate ECDIS usability, as outlined in the Method section.

5.1 Task Results

The following section presents the results of the task section of the experiment. Those results that do not take into account the subjective opinions of the group, but rather their ability to perform the three tasks they were given.

5.1.1 Bearing Calculation

The students were asked to find their location by taking a bearing and plotting it on the ECDIS. The coordinates they gave were then mathematically analyzed and it was found how accurately they managed to take a bearing. Please note that the “participant numbers” shown in the figures below are assigned randomly for each figure and are by no means to be interpreted as assigning names/uniqueness to individual participants. In other words, "participant 1" might be a different subject in two different figures.

Below, Figures 4 & 5, present the subjects with very little experience working with ECDIS (defined as 10 hours and under), on the T-ECDIS. Figure 5 shows how many subjects, percent-wise, obtained a correct position.

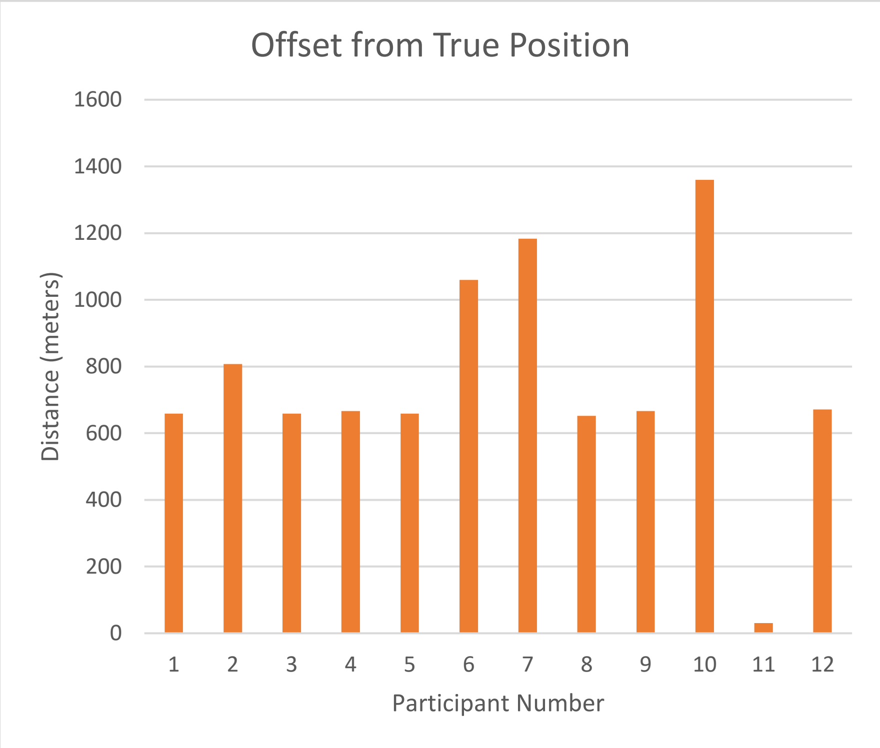


Figure 4: Offset from True Position on T-ECDIS

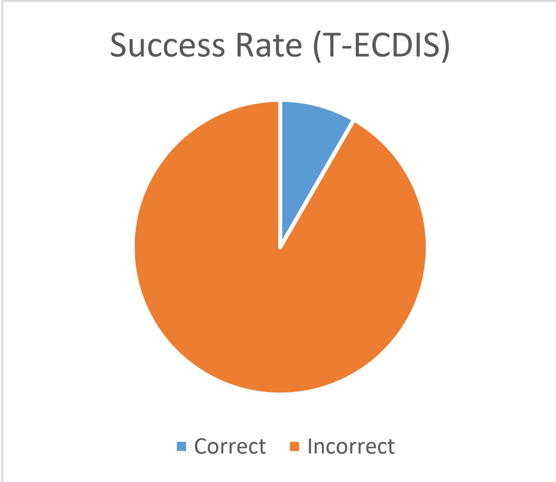
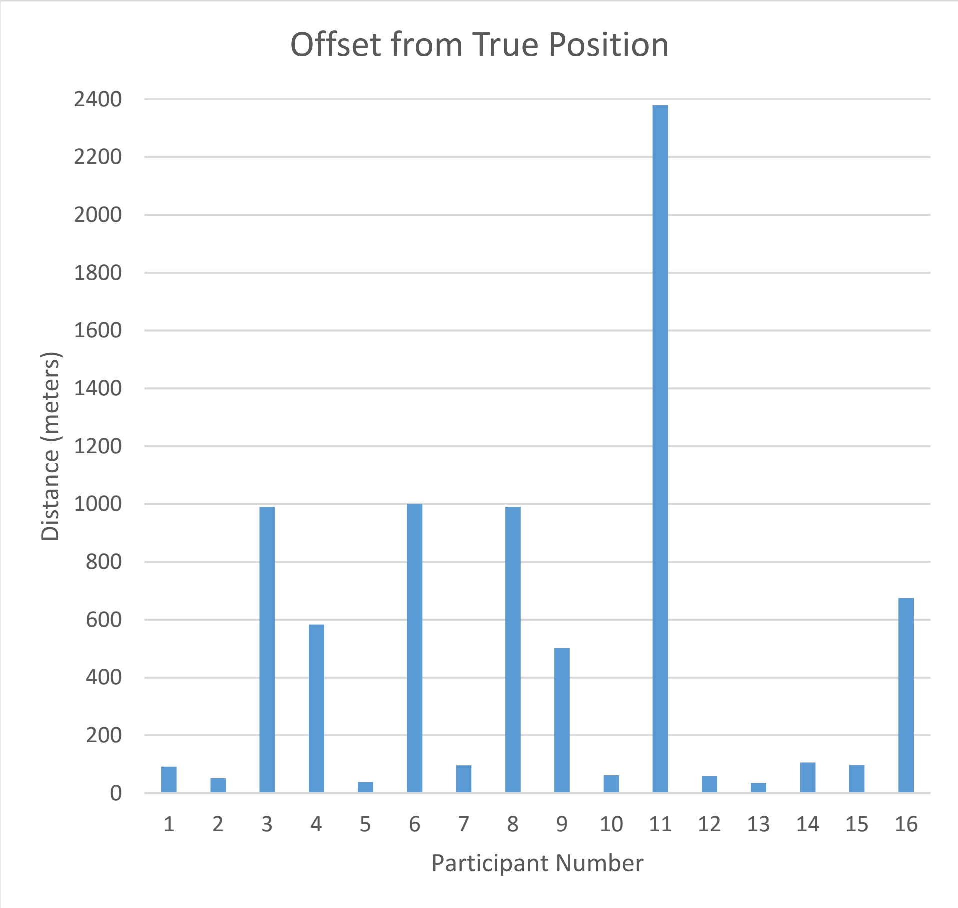


Figure 5: Bearing Success Rate on T-ECDIS

As can be seen, none of the participants managed to find the vessel's correct position except one. The mean time it took the participants to complete the task was 6.26 minutes, with a mean offset of 756 meters.

On the other hand, the group that used the K-ECDIS system achieved the following results. They are presented in the same manner as above, showcasing the users with little experience.



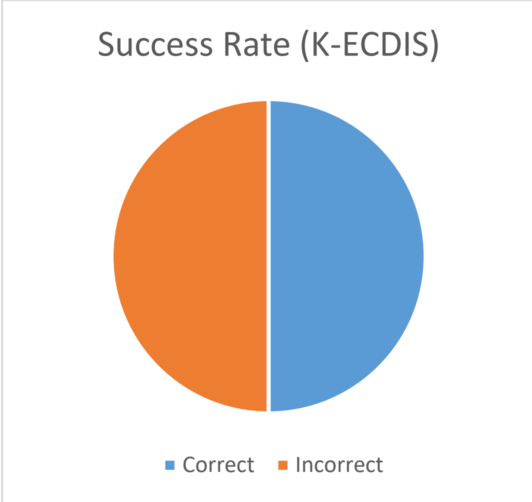


Figure 6: Bearing Success Rate on K-ECDIS

Figure 7: Offset from True Position on T-ECDIS

As can be seen above, there is a statistically significant increase in the number of subjects who managed to find the correct position. It is unavoidably true that, given the sample size, this could be a coincidence. Therefore, this data should be taken as a suggestion of the truth, rather than a firm empirical conclusion. However, for the bounds of this paper, this trend will not be discounted as mere coincidence. Lastly, the mean time taken to complete the task was 7.18 minutes, and the mean offset was 358 meters (discounting number 11, since it is an outlier). It should also be noted that three participants in total could not even complete the task, across both T-ECDIS and K-ECDIS groups.

However, it is perhaps difficult to see the concrete differences between the two groups only using graphical representations. To confirm trends that seem to appear in the figures, a firmer, more statistical approach is taken to put the numbers into perspective. This is done through a "T-Test". A t-test is an inferential statistic used to determine whether there is significant difference between two groups and how they are related. It is widely used for hypothesis testing and is therefore ideal for this dataset (Hayes, 2023). The dataset was run through IBM's SPSS software to obtain the following results.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Diff. (m)	Equal variances assumed	3,190	,086	1,350	26	,094	,189	271,22917	200,84898	-141,62182	684,08016
	Equal variances not assumed			1,467	23,798	,078	,155	271,22917	184,82625	-110,40465	652,86298

Figure 8: Independent Samples Test of Bearing Calculations

Group Statistics

	T or K	N	Mean	Std. Deviation	Std. Error Mean
Diff. (m)	1,00	12	756,1917	334,41105	96,53616
	2,00	16	484,9625	630,44763	157,61191

Figure 9: Group Statistics of Bearing Calculations

The figures above describe the following. The likelihood of the null hypothesis being true (the hypothesis that there is no difference between the two groups) is 8.6%, meaning that statistically it is very likely that there are differences within the systems that, such as their design and user interface, bring forth differing results from a homogenous group, which is what the subject group is supposed to be. However, within official circles, the likelihood has to be lower than 5% for the results to be significant. The dataset in this paper unfortunately falls just shy of this mark. This is very likely due to the small sample size available for the experiment. Nonetheless, the results allude to significant differences between the systems. At the very least, when plotting and calculating bearings. Further differences can be seen in the "Group Statistics" table, which shows that the mean and the standard deviation of the two groups is very different, with subjects who used the K-ECDIS system achieving far better results.

Overall, the results point to significant differences between the usability of K- and T-ECDIS models, with subjects who used the K-ECDIS model far likelier to secure a correct position. The validity is swayed by the reduced sample size, but the topic is worth investigating further.

5.1.2 Route Plotting

The following group of pie charts represents the number of subjects who successfully managed to complete the route-plotting subtasks, out of the group with little experience who used T-ECDIS.

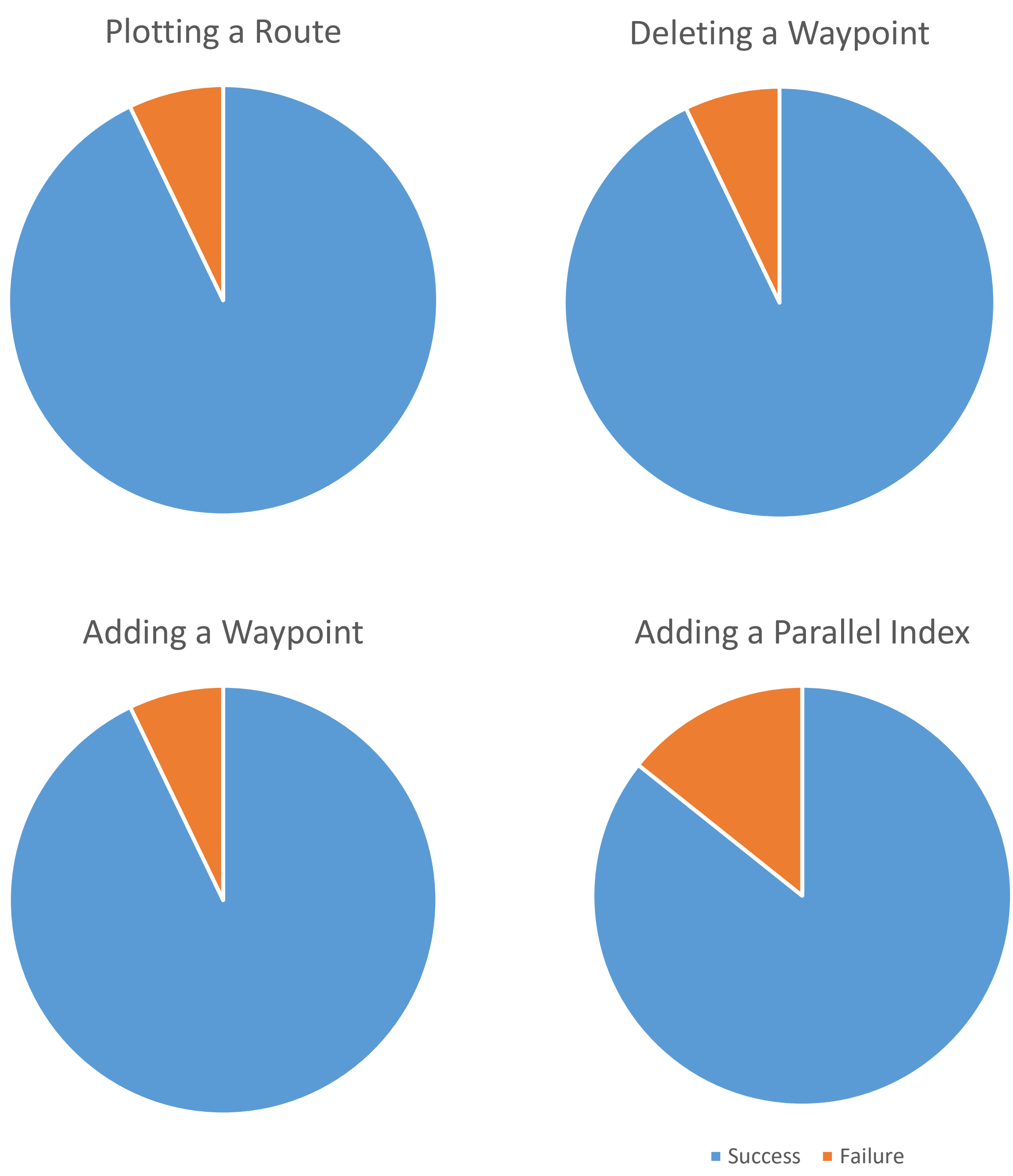


Figure 10: Success Rate of Route Plotting on T-ECDIS

Above it can be seen that the vast majority of subjects did not have an issue with attempting route plotting. Notably, the failure for the addition of a parallel index is greater than in any other category. The same charts are given below for the group who used K-ECDIS.

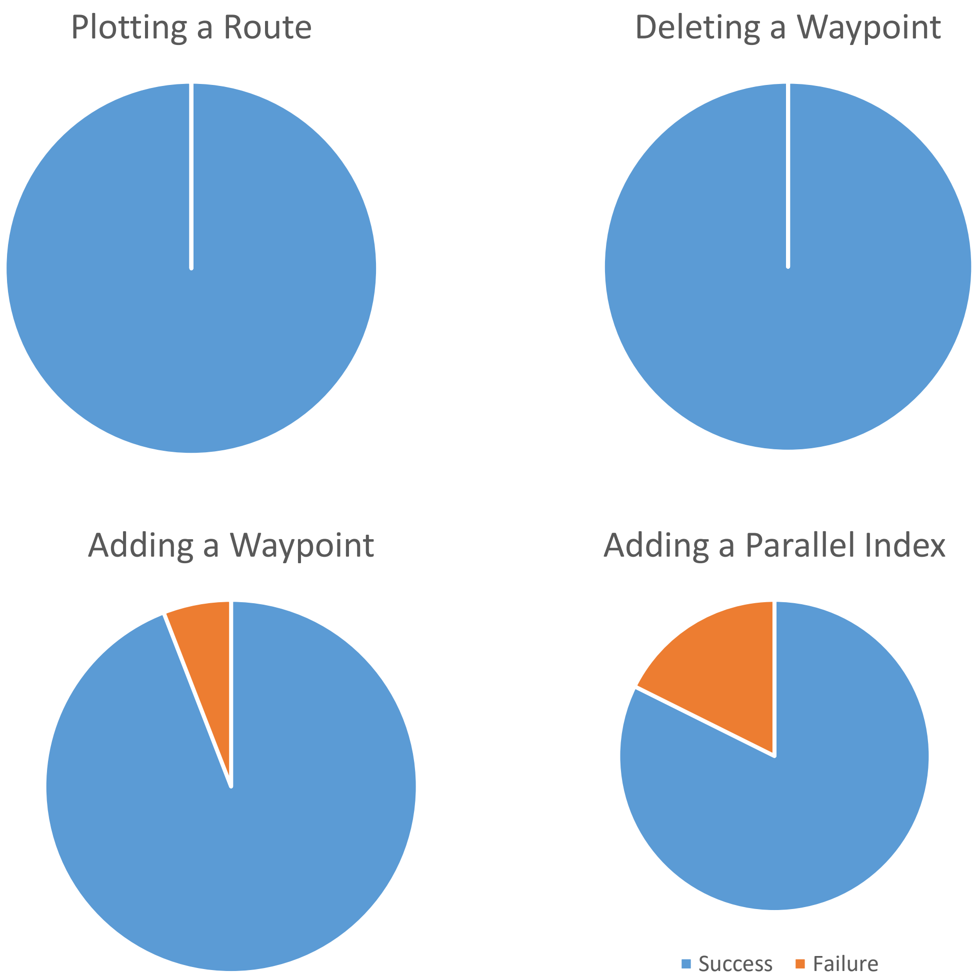


Figure 11: Success Rate of Route Plotting on K-ECDIS

As can be seen above, most of the subjects were successful with plotting a route, and entirely successful with the first two tasks. However, notably, the plotting of a parallel index remains the task with the biggest rate of failure across both ECDIS systems.

To supplement the data above, the amount of time it took each subject to carry out the task is presented below.

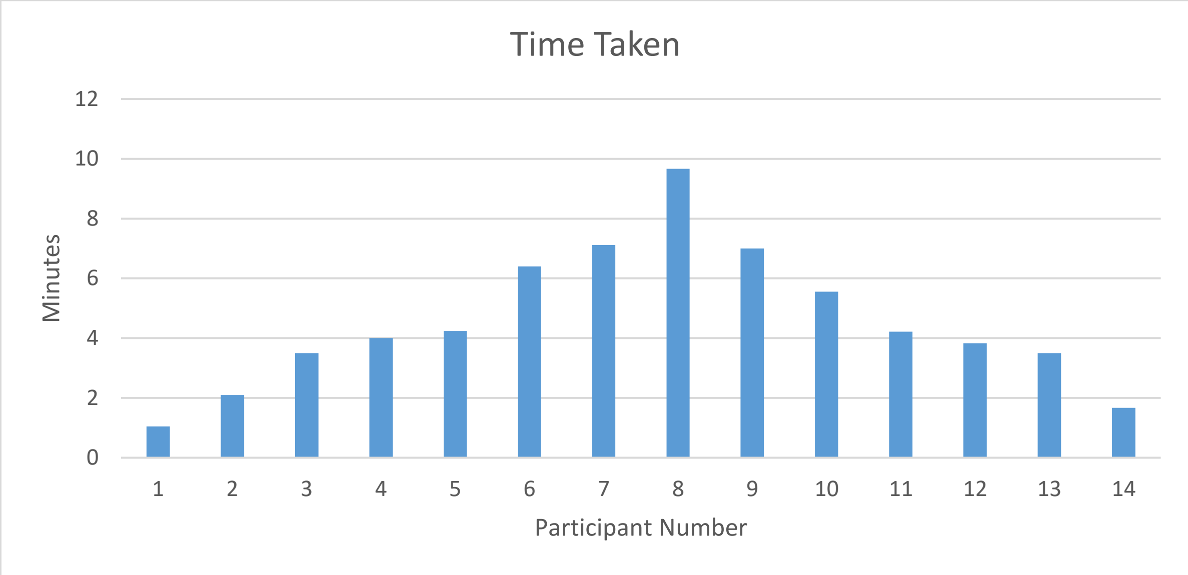


Figure 12: Time Taken to Complete Route Plotting on T-ECDIS

The figure above shows that there is a fairly even distribution in the time it took participants to complete the route-plotting tasks, with no particular outliers. The mean time remains at around 4.6 minutes. The same type of data is presented below, except for the group that used K-ECDIS, also with little experience.

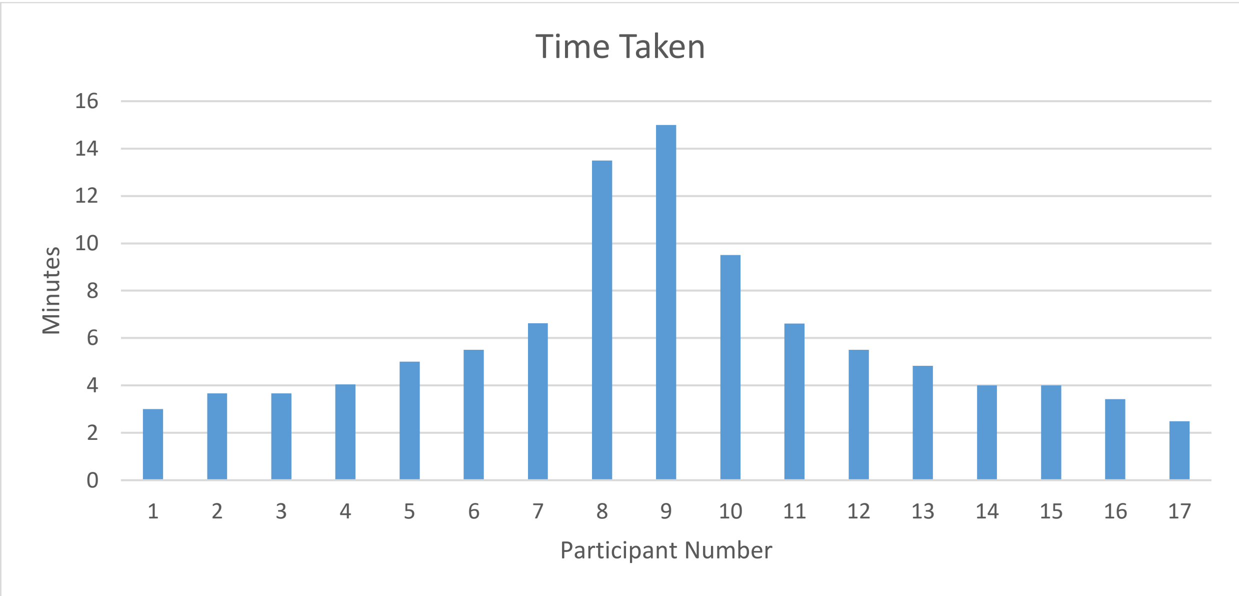


Figure 13: Time Taken to Complete Route Plotting on K-ECDIS

As can be seen, this distribution is fairly similar to the one for T-ECDIS, however the mean time is higher – staying at around 6 minutes. These two datasets were also treated to a t-test, and the results are seen below.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
VAR00003	Equal variances assumed	,949	,338	-1,206	29	,119	,238	-1,34440	1,11482	-3,62446	,93566
	Equal variances not assumed			-1,254	27,883	,110	,220	-1,34440	1,07238	-3,54149	,85270

Figure 14: Independent Sample Test for Route Plotting

Group Statistics

	VAR00002	N	Mean	Std. Deviation	Std. Error Mean
VAR00003	1,00	14	4,5595	2,36952	,63328
	2,00	17	5,9039	3,56824	,86543

Figure 15: Group Statistics for Route Plotting

The test confirms the results outlined in the bar graphs – namely that there is no major difference between the amount of time it took the subjects to perform the associated tasks. The K-ECDIS group was, however, a little slower. Notably, the K-ECDIS group also had a slower mean time in the plotting of bearings in section 5.1.1.

Overall, the results indicate that both systems yield approximately the same results when it comes to plotting routes, except that both systems had higher failure ratings for setting in a parallel index. This might be because the name is not standardized, and it is named differently based on the system.

5.1.3 Finding an Unknown Map Symbol

The subjects were asked to find the meaning of a pre-selected map symbol. They were advised of its location and told to write the symbol's meaning down (which was a north cardinal marker). The results from the T-ECDIS and the K-ECDIS are presented below.

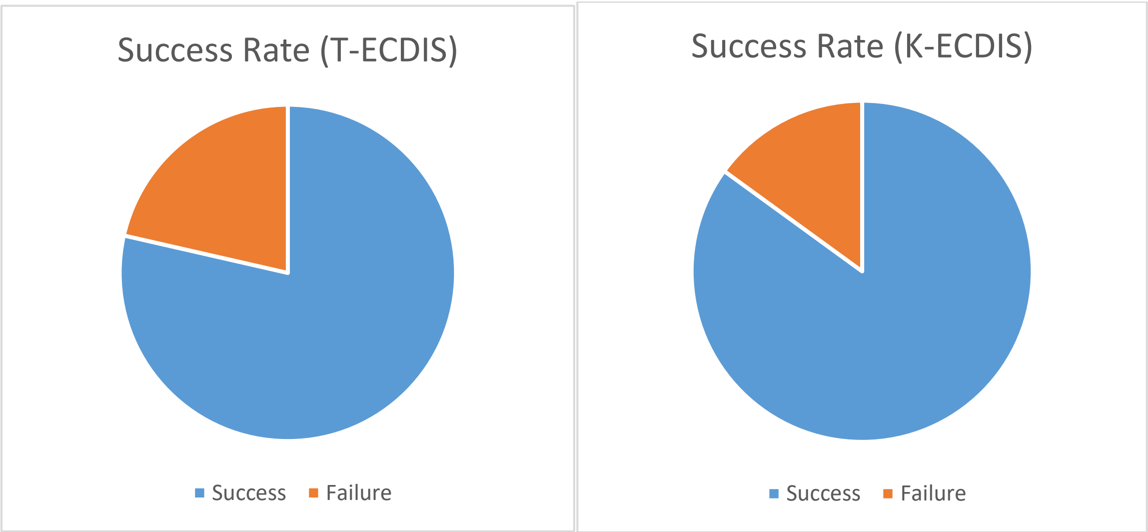


Figure 16: Success Rate of Symbol-Finding (both systems)

As can be seen in the pie charts above, there was a non-insignificant number of participants who did not manage to complete the task. The relative amount was greater in the group that used T-ECDIS. Another key part of the data is of course the time it took the participants to arrive at their answers. This data is presented below for both systems.

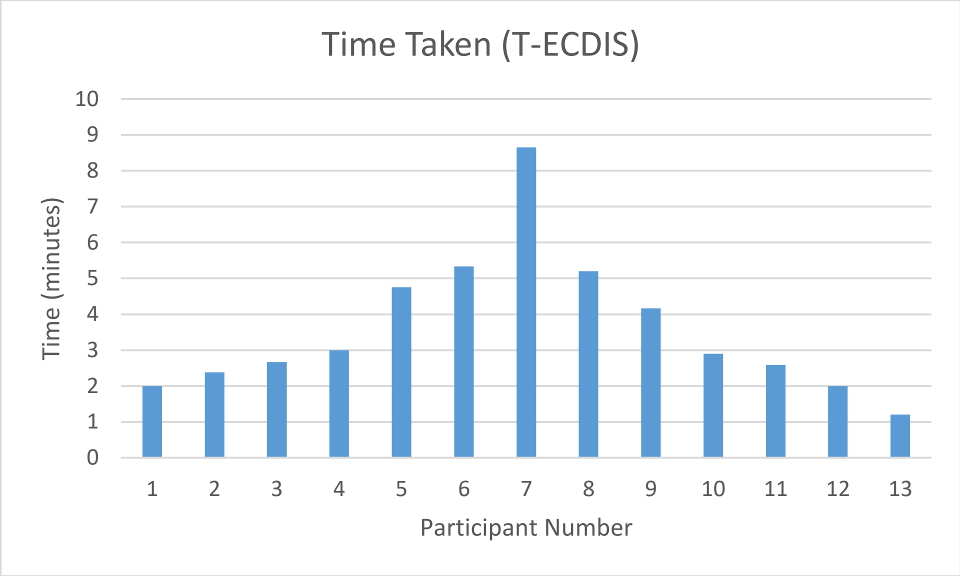


Figure 17: Time Taken for Symbol-Finding on T-ECDIS

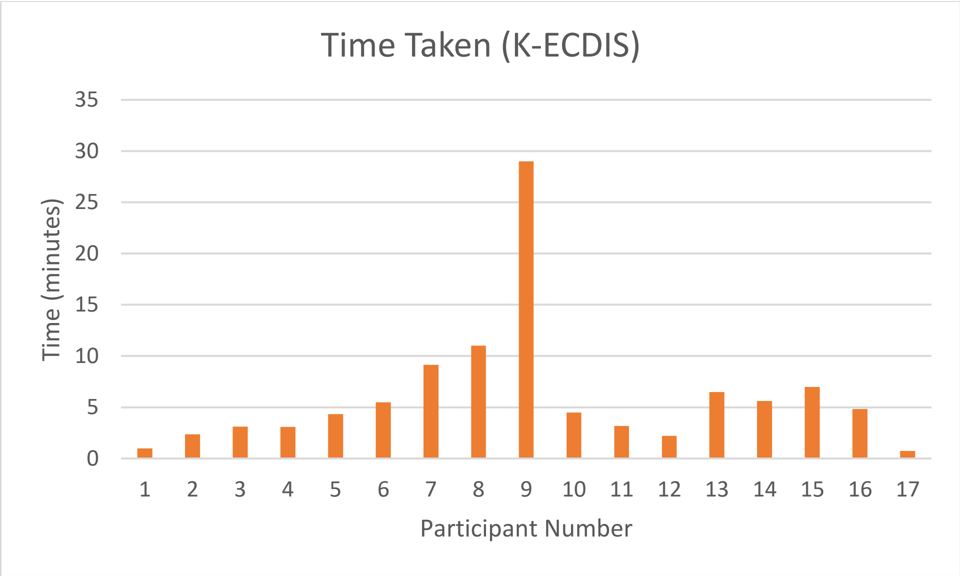


Figure 18: Time Taken for Symbol-Finding on K-ECDIS

The figures above show that the time taken for subjects to complete the task was relatively low. Participant number 9 in the K-ECDIS group should be considered an outlier and therefore not included in the calculation of the mean time. Regarding that, the mean time for T-ECDIS was 3.6 minutes and 4.6 minutes for K-ECDIS. The mean time is nonetheless surprisingly high for the simplicity of the task.

Overall, the results corroborate with those of the first two tasks. In the sense that the K-ECDIS subjects regularly score higher than their T-ECDIS counterparts. The validity of this conclusion is of course limited by the sample size, however the trend that emerges very clearly points to K-ECDIS being a system that yields better results. However, the K-ECDIS system is also notably slower to use in all cases, which comes with its own drawbacks in time-critical situations. However, it may be argued that a correct position in good time is better than an incorrect one quickly.

5.2 Survey Results

This section presents the results of the surveys in the study. What is meant by this is specifically the results from the task-load index and the digital survey. The subjective opinions of the users are important statistics to take into consideration regarding the usability of the user-interface and system in general.

5.2.1 NASA TLX Index

The figures below present the average score that the participants gave to each of the 6 categories regarding the tasks they needed to accomplish on the T-ECDIS.

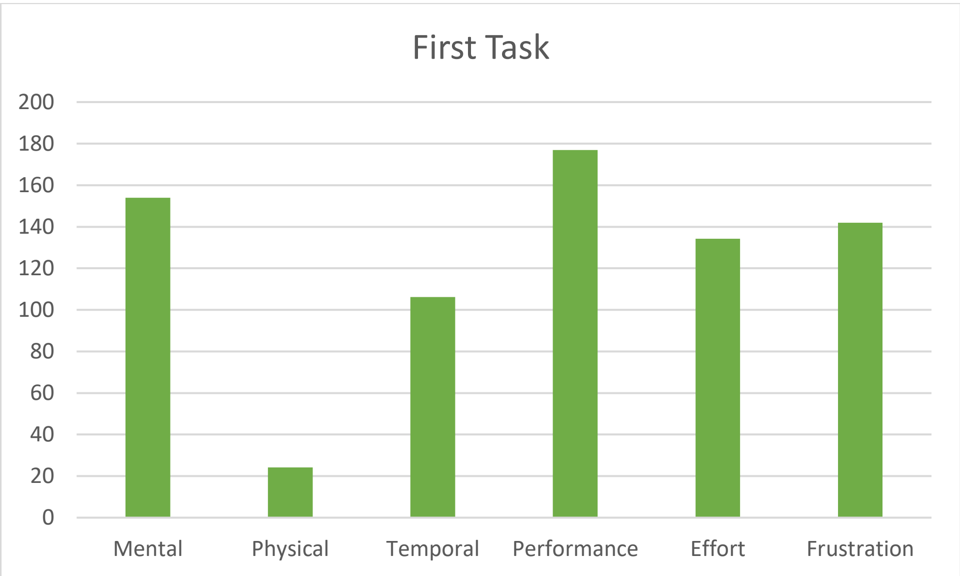


Figure 19: TLX of First Task on T-ECDIS

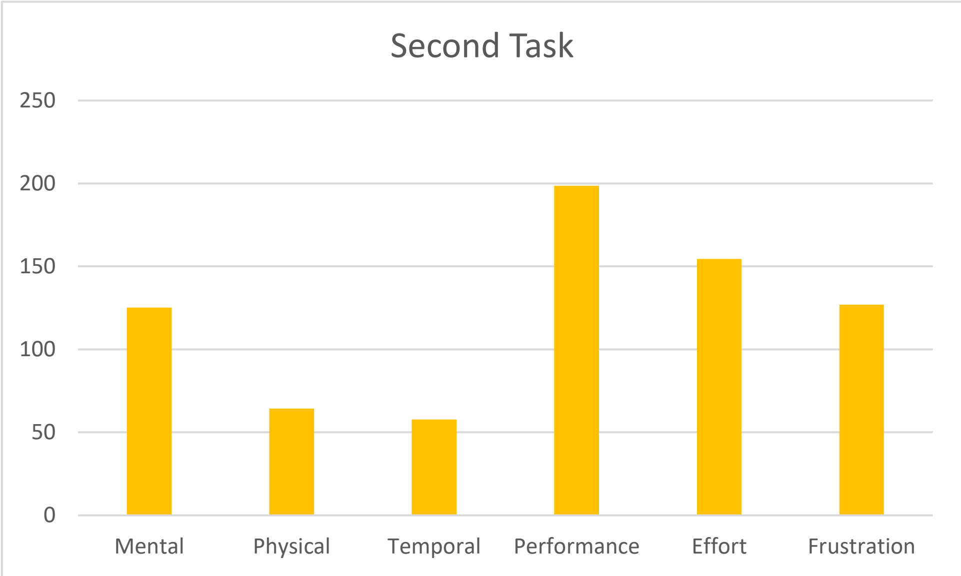


Figure 20: TLX of Second Task on T-ECDIS

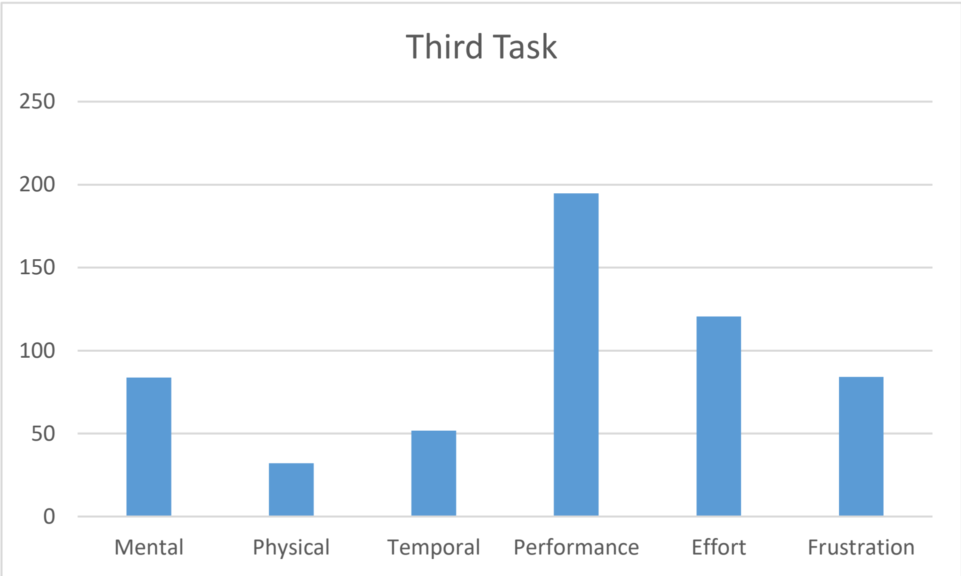


Figure 21: TLX of Third Task on T-ECDIS

The task-load index presents a unique way for this paper to give numerical analysis to a subjective process. It can be seen that consistently across the tasks, the "Performance" section was the one with the highest score. The higher the score in the performance section, the better the participants think they did in the corresponding task. It rests at around 200 points for nearly all the three tasks, except for the 1st one, which has a slightly lower score of around 180. The next-highest scoring categories were, generally, the effort and frustration categories, with effort usually being higher except for the first task where frustration was higher. What is meant by effort and frustration is the effort taken to achieve the results, and the frustration that the user experienced underway. After that, generally, the mental demand category was highest, except for task one in which it outranked both effort and frustration. Lastly come the temporal and physical categories, as should be expected since operating an ECDIS is not a physically strenuous process, and the temporal demand placed on the user, especially in the contexts of this study, were extremely low. What is interesting is the scoring of the effort and frustration categories in comparison to everything else – these categories consistently scored in the same range as the participant's opinion of their performance. This suggests that effort and frustration are significant parts of the user experience. In addition, the mental demand category scored highest in the first task, suggesting it was notably more strenuous for users in terms of cognitive load. It is also interesting that the participants rated their performance only slightly lower in the first task, given the fact that only 1 subject was able to take a bearing correctly. This suggests that it was difficult for users to verify the success of their performance, meaning that most users did not realize that they did not take a bearing correctly. The last significant feature is perhaps the unusually high scoring of the temporal category in the first task. This is unusual since the lay of the experiment presented no particular time pressures upon the subjects. This scoring could perhaps refer to the time it took to accomplish the task, since it was, on average, higher than in any other task.

The results for the K-ECDIS group are outlined below.

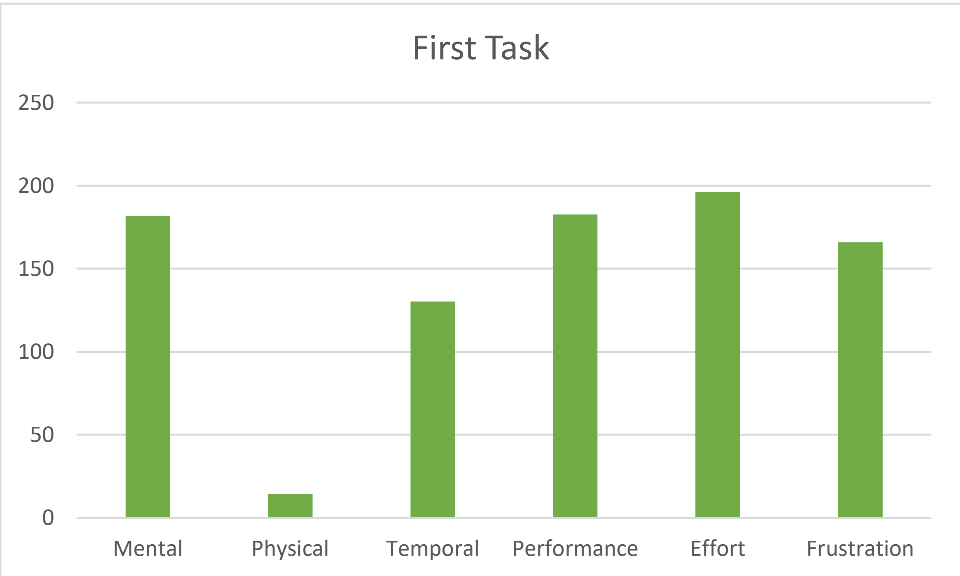


Figure 22: TLX of First Task on K-ECDIS

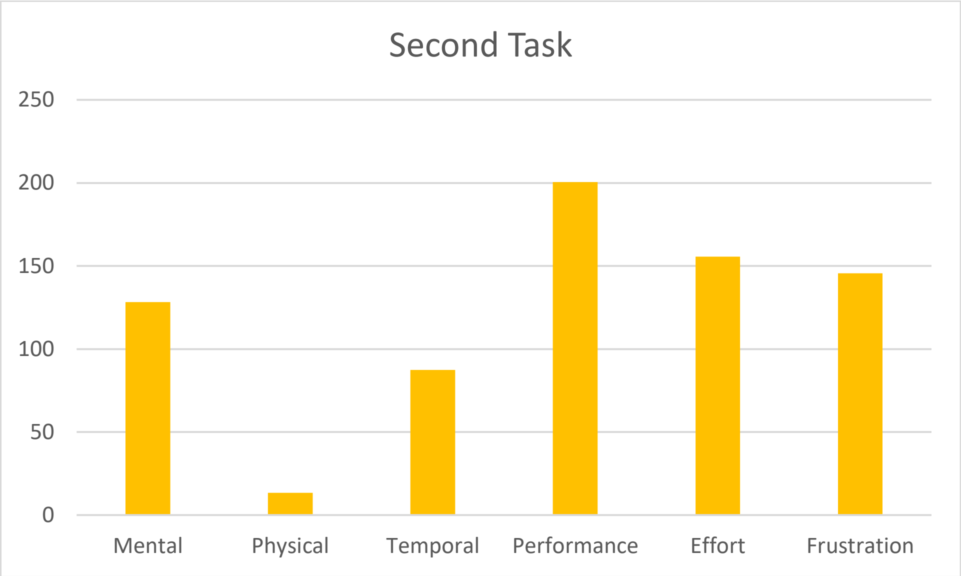


Figure 23: TLX of Second Task on K-ECDIS

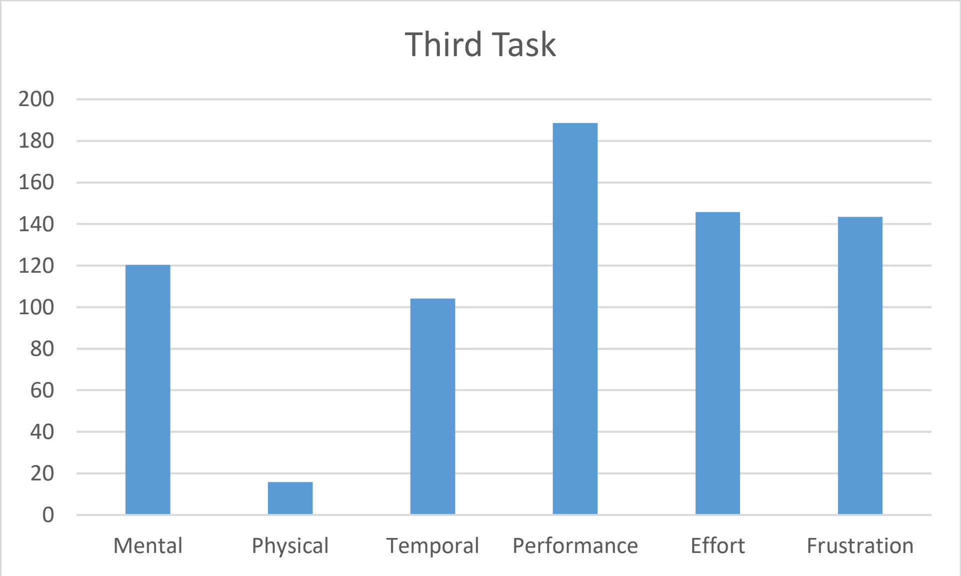


Figure 24: TLX of Third Task on K-ECDIS

The figures above bear a likeness to the ones previously seen for the T-ECDIS group, however there are several notable differences. The performance category is generally the highest, scoring, once again, around the 200 mark. Categories for effort and frustration follow in second, and the category for mental demand follows 3rd, with temporal and physical staying at the bottom. This is expected, since the tasks did not change, but rather the system on which they were carried out. There is a general increase however, in the scoring of both effort and frustration, notably in the first task, where effort scored even higher than performance. Overall, frustration and effort remain a central part of user experience. However, the performance scoring appears more accurate this time around, since more than one subject was able to note down a correct position for their vessel. This suggests that it was easier, or clearer to the user, whether they did or did not manage to successfully take a bearing. The mental demand category can once again be seen to be increased in the first task, alluding to its more difficult nature. And lastly, the temporal category remains curiously high-scoring in the first task, except this time it is also mirrored in the third task. This is unusual since the task does not involve any time pressure, and the amount of time taken to complete it, on average, was actually the lowest out of all the tasks. This may suggest that the participants interpreted the category in a different way than was intended by the index.

In general, however, both sets of figures present a reality in which mental demand, effort, and frustration dominate the user experience. It is, of course, expected for there to be a certain degree of frustration when working with a software program, but the relative scoring of the subjects shows that it is perhaps greater than would ideally be desirable. The scoring in undesirable categories is notably higher in the K-ECDIS system.

5.2.2 Survey

The results from the digital survey carried out by the participants will be presented in this section. The survey was designed to capture the users' experience and opinions regarding the use of ECDIS software. The opinions of all the study's subjects will be included in the results, regardless of experience. In this way, the survey will be able to capture a broad-spectrum opinion. The survey was conducted in a way where subjects were asked to either agree or disagree with a statement on a 10-point scale. '1' meaning "Strongly Disagree", and '2' meaning "Strongly Agree". The results are presented as the median score for each question from the 17 participants who answered the surveys. The median is favored above the mean in this case, as it is thought it will reduce the bias from outlier-values. The results for the T-ECDIS survey are shown below, followed by the results from K-ECDIS.

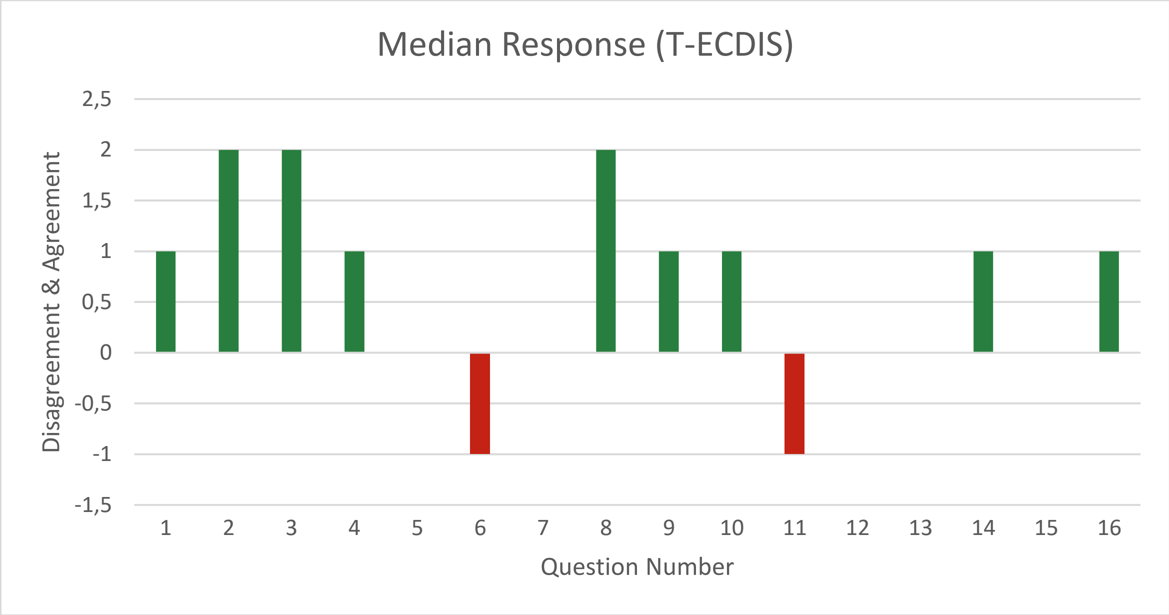


Figure 25: Median Response to Survey (T-ECDIS)

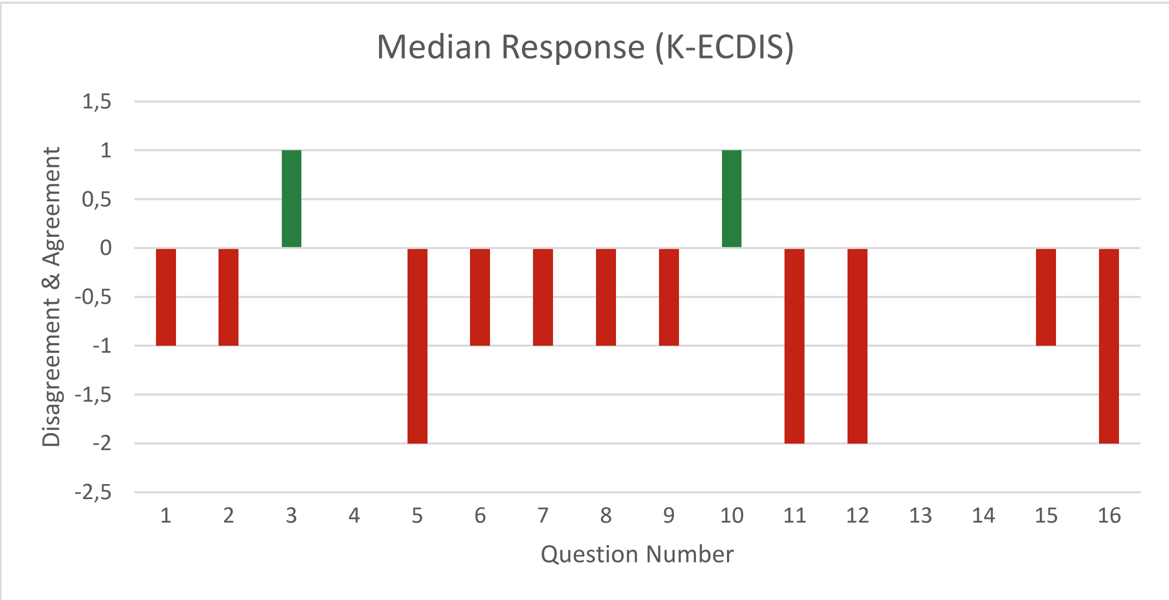


Figure 26: Median Response to Survey (K-ECDIS)

The questions that the numbers in the figures represent are listed in the Table below.

Question 1	The system is easy to use.
Question 2	The system is easy to navigate.
Question 3	The system is easy to learn.
Question 4	The system is intuitive.
Question 5	The system is forgiving to user error.
Question 6	The system design is modern.
Question 7	The system does not use unnecessary abbreviations.
Question 8	The system-design is straight-forward.
Question 9	The system design is not unnecessarily complicated.
Question 10	Only the most relevant data is displayed first.
Question 11	The system design is as good as it can be.
Question 12	The system is designed to be as easy-to-use as possible.
Question 13	It is easy to keep track of all of the information on the screen.
Question 14	The screen is not cluttered.
Question 15	The system design is accommodating to time-critical operations.
Question 16	The system design is accommodating to stressful operations.

Table 1: Digital Survey Questions

As can be seen, there is considerable difference between the two figures. One could almost think that they are mirror versions of one another – so strongly do they proclaim their differences. Figure 25 generally tends to agree with all of the statements – thus having a generally positive outlook on the design of the T-ECDIS system. The only exceptions to this were in questions six and eleven; relating to the modernity of the system and the opportunity for continued improvement. The subjects seemed to think positively of the system but did think that it was not what they considered “modern”, and that on the whole, the system could be improved. This stands in contrast to Figure 26, in which the subjects of the experiment had a generally negative view of the K-ECDIS system. In fact, every response disagreed with the statements, except for two instances – in questions three and ten. The subjects of both systems agreed on the fact that their systems were easy to learn, and that they presented only the most relevant data first. However, the strong disparity between the data sets suggests a strong difference in the design, and therefore the user experience of the two different ECDIS systems. The results of Figure 26 would suggest that K-ECDIS is more difficult to use, which is in fact corroborated by the results from the NASA TLX. Figures in the TLX section continuously showed that the categories for mental demand, effort, and frustration were greater in the K-ECDIS system than their equivalents in the T-ECDIS system.

Overall, these results suggest that the usability of the K-ECDIS system should be improved, and that even though the T-ECDIS comparatively scored well, the subjects still thought that were was room for improvement.

6 Discussion

In this section, the findings of the study will be discussed, correlated, and corroborated. That is, the findings from both the literature study and the experiment.

Part of the literature study found that some ECDIS systems were not intuitive to use, and it was even cited as one of the contributing factors to the grounding of the Nova Cura. This was confirmed by the experimental results in the sense that both ECDIS systems that were tested placed a significant cognitive load on their operators. This can be seen in the results from the TLX which recorded high levels of mental demand, effort, and frustration. However the digital survey was less conclusive, and even suggested that the T-ECDIS system was more intuitive than unintuitive. However the extremely high failure rate in the bearing calculation task, on both systems, would tend to sway the judgement towards a lack of intuitiveness. In addition, the results of the experiment confirm the extent of the problems that could possibly be caused by a lack of standardization.

The literature study found that there exists a very diversified market of ECDIS manufacturers, resulting in a lack of standardization between systems. This decreases the user-friendliness of systems by eliminating familiarity and forcing seafarers who frequently switch ships to learn to use possibly very different systems. The experimental results confirm this when one looks at almost anything. Between two different systems, the ratings of the TLX point to a significantly increased mental demand, effort, and frustration in the K-ECDIS. However it is worth noting that both systems exemplify high scores in these categories. The results of the survey corroborate this conclusion by showing that the K-

ECDIS system is far inferior to the T-ECDIS in terms of usability. The participants of the study found it to be worse in every single statement, except one (number ten). However, the K-ECDIS system is not worse across the board. The quantitative results in all three tasks were generally significantly better than the T-ECDIS counterparts. This can especially be seen in the failure rate of the bearing calculation task. This goes to show how different system design can have a significant impact on user performance. Since two groups of subjects of similar experience and professional pedigree executed the same tasks on two different systems, this goes to suggest that it was the systems themselves that were responsible for the discrepancy. However, further study should be conducted to confirm this, with a larger sample size. Overall different systems offer different advantages, however for the purposes of maritime safety a standardization would level the playing field, so to say, and could lead to a better user experience.

By themselves, the results of the experiment confirm the conclusions of the literature study, even though the limited sample size of the experiment warrants further study on the subject. The bearing task is an essential one onboard and is one of the performance requirements of ECDIS systems. The high failure rate on both systems suggests that either the experience of the subjects is at fault, or the software itself. What is more likely however is that both are at fault. This can be seen in real-world examples of unfortunate and entirely avoidable maritime accidents. While this study cannot say much as to the skills of seafarers, the deficiencies of software are abundantly clear in the data that has been collected from surveys, especially the TLX. This data points towards a system where mental demand is high, effort is high, and frustration is also high. In safety-critical systems such as ECDIS, manufacturers should strive to keep these categories as low as possible and the paper hopes to highlight the need for further research into usability and ergonomic design. This is shown not only through the results of the experiment, but also through the aspects of the literature study that have yet to be mentioned.

The literature study also found that ENC quality is not highlighted to the operator by the user interface, which creates serious problems for safety and has already led to several serious accidents. In addition, some user interfaces offer too much functionality and too much information which can over-saturate the user. The MAIB & DMAIB study found that the operation of ECDIS warrants use of serious cognitive resources, which was confirmed in the experiment by the TLX scores that showed a large mental demand placed on the operator. One can imagine how this load becomes even greater when the operator is navigating in congested waters and must engage in many different tasks at the same time. It is from this viewpoint that the paper seeks to recommend further scrutiny to human-centred design in ECDIS systems.

This overwhelming evidence that points towards flaws in user-centred design begs the question of why it has yet to be resolved or addressed. This may very well be because of the unique conditions of the maritime technology market.

Manufacturers use the mandatory specific-type training as a crutch. In no other branch of the software industry would the user experience be so neglected. In a normal software market, the software must be as easy-to-use, as intuitive, and as user-friendly as possible, otherwise the customer would simply opt for another software that is more convenient. However, aboard a ship, that is not as easy. ECDIS systems are now most commonly fitted at shipyards. They are therefore chosen by the owners of the ship and/or the shipyard, and *not* the team of officers which will be using it (i.e.: the actual users). This creates a disparity between the wants and needs of the users and their ability to communicate those to the manufacturer. Refitting an ECDIS system is a very costly and lengthy process, and while it is being done, the ship might not be considered seaworthy which could lead to loss of hire for the shipowner. Refitting an ECDIS simply because it is "not user friendly" could never be reasonable enough grounds for a refitting. Given that the lifespan of an ECDIS can exceed well over a decade, this means that improvements in software and design have a very lengthy implementation rate. This artificial lack of demand for better systems is why manufacturers do not place usability on their list of priorities – rather choosing to focus on the functionality of the system which is the aspect of the system that is most important to a potential shipowner. However, as this paper has endeavoured to show, an ECDIS system without focus on the user and their needs, can lead to an increased risk of ECDIS-assisted accidents. In fact, the lack of user-feedback mentioned herein is perhaps central to the problems previously discussed regarding alarm fatigue in ECDIS.

According to the examination of a variety of sources in the "Literature Study" section of this paper, it was found that alarm fatigue and its associated coping mechanisms are a prevalent issue within the maritime sector and ECDIS design. Alarm fatigue, and alarms in general, are a key part of both the user-interface and the user experience. The study conducted by MAIB & DMAIB found that alarms were a consistently bothersome part of most ECDIS systems, but due to the lack of communication between actual users and manufacturers, this issue is not taken into account when shipowners outfit their ships. Usually alarm fatigue would be addressed through accident reports, as is common in both the medical and the civic aviation industry. An accident report in those areas would very clearly point to the ignorance of an alarm as the principal cause of an incident. This is because both of those fields have a very small margin of error. When a mistake is made, it leads to terrible consequences. Accident reports in the maritime industry feature no shortage of alarms being disabled, ignored, or misunderstood. However, the key difference is that a maritime accident is very usually the result of a series of errors. It's very typical that inattentiveness, fatigue, and bad judgement calls are cited as the primary causes of an accident. These issues, which are typical of the industry, help to obscure the secondary causes such as alarms being disabled or ignored. Even then, these secondary causes are ascribed to the low levels of professionalism onboard, as opposed to being treated for what they actually are – symptoms of a larger systemic flaw across ECDIS systems. This can be seen perfectly in the grounding of the Ovit. A report by Safety4Sea, a long-standing maritime news agency, reported that the grounding of the Ovit was mainly due to the incompetence of the officers, but unlike the official report by MAIB, failed to even mention the fact that the audible alarm was disabled and that the crew was well aware of this fact (Safety4Sea, 2019). This way, other issues obscure important flaws in the user experience. What needs to be understood is that the maritime technology sector is different to a regular technology market, as previously stated. A bad user experience is simply uncomfortable when it is a laptop that one uses, but when safety-critical systems create an uncomfortable work environment for users, this can be a contributing factor to loss of life, property, and pollution. In this way, ignoring the user experience leads to the retention of a serious safety problem. The lack of feedback that creates bad, non-human-centred design in ECDIS also leads to the perpetration of alarm fatigue.

On the whole, while ECDIS meets the basic standards for usability, it's user interface, design, and user experience remain staggeringly behind contemporaries in other industries. In this way, the user interface aids the user in the operation of the software only on a basic level which leaves a lot of room for improvement in the future.

7 Conclusion

The scope of this paper is unfortunately limited in resources; however it is hoped that the conclusions of this paper warrant further research and attention by the industry. It has been shown that ECDIS software does not follow human-centred design principles, and in its current state the lack of ergonomic design creates a bad user experience, and contributes to compromise the safety of marine vessels, as well as helping to hide flaws such as alarm fatigue. It is hoped that this paper is taken to be the indication of a problem that merits serious attention. Nonetheless, the limited scope of the paper is acknowledged, and it is therefore that there exist a number of further improvements further research could incorporate.

The paper was limited in the diversity and number of subjects that could be interviewed. It would be very useful to conduct a survey, or a similar usability experiment on a larger demographic with a wider array of experience and on different vessels and systems. The study conducted by MAIB & DMAIB is a peerless example of the way that further insight could be gained into the real-world operation of ECDIS by seafarers. It is advised that a report in the same vein would be useful in ascertaining the true state of usability in ECDIS design.

Furthermore, the literature study was limited to a general and fairly case-by-case approach. A study of usability by an expert in the field would be far more relevant and gainful. In the sense that the expert would assess real-world ECDIS systems.

Based on the conclusions of this paper, it is hoped that some benefit might be extracted by the manufacturers of ECDIS systems. By looking at the concrete problems mariners face, the issues brought up in this paper could very well be used as guidelines to further developments of ECDIS software. Of all things, it is hoped that the opinions of seafarers will be taken into consideration when designing future software, as it has been shown that there exists a disparity between the actual users of the software and the buyers. Regarding this lack of feedback channels, it would also be beneficial if a feedback channel could be established wherein seafarers could communicate their specific operational needs to the manufacturers, as currently such a channel does not practically exist.

In conclusion, it is hoped that this paper can bring light to an area of maritime technology that remains unexplored despite its relevance to safety at sea.

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