

Developing a High-Speed Craft Route Monitor Window

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Abstract. High-speed navigation in littoral waters is an advanced maritime operation. Reliable, timely and consistent data provided by the integrated navigation systems increases safe navigation. The workload of the navigator is high, together with the interaction between the navigator and the navigation system. Information from the graphical user interface in bridge displays must facilitate the demands for the high-speed navigator, and this article presents how eye tracking data was used to identify user requirements which in combination with a human-centred design process led to the development of an improved software application on essential navigation equipment.

Keywords: Navigation · High-speed · Eye tracking · GUI · HCD

1 Introduction

Conducting a safe high-speed passage in littoral waters is a demanding task. With increasing demands for efficiency, and increasing use of technology and Human Machine Interaction (HMI), the daily job for the navigator has changed. Good Situational Awareness (SA) for the navigator has been emphasized as a critical component to avoid navigation accidents [1], and thus there are several technological initiatives aimed to enhance the SA of the navigator.

The extensive use of technology on ship bridges has caused concern about poor system usability for human interaction. One concern relates to how new technology aiming to increase the safety of operation, actually ends up doing the opposite [2]. Involving the human element in the design of systems is therefore imperative to minimize the potential human error in the operation and to increase safe navigation.

Eye tracking technology is a tool that can inform the designer about operator behaviour. It can monitor the eye's movement, and the collected data can be analysed to identify what kind of equipment that is used and how much time the navigator addresses that specific equipment. Analysing the data further can identify equipment and interfaces that steal time from the navigator's main task, and consequently lowers the navigator's SA. This study gives an example of how collecting and analysing Eye tracking data in combination with a Human-Centred Design (HCD) process resulted in

a new and more user friendly design of the High-Speed Craft (HSC) route monitor window.

2 Background

High speed navigation has evolved since the first Hydrofoils in the early 20th century, and in the 1990s with catamaran hulls. A HSC is defined as a craft capable of maximum speed, in knots (kn), equal to or exceeding [3]:

$$7.192 x \nabla^{0,1667}$$

∇ = volume of displacement corresponding to the design waterline (m³).

For the Skjold-class in Fig. 2, this implies:

$$7.192 x 641^{0,1667} = 21,1 \text{ kn}$$

Which concludes that the Skjold-class is a HSC, since the top speed is more than 21,1 kn.

The Norwegian coastline has been used to transport people for centuries, where the last decade has shown an increased need for even more efficient (faster) journeys. Norwegian yards and ship owners have a long tradition of building, utilizing and optimizing HSCs, most recently shown by the first hybrid HSC “Vision of the Fjords” [4]. Similarly, The Royal Norwegian Navy (RNoN) has a long tradition of operating HSCs, such as Fast Patrol Boats, to deter an enemy from attacking from the sea towards the coast. The challenging task of navigating a HSC in littoral waters has been emphasized, especially when it comes to the workload for the navigator [5]. The main difference between civilian and military maritime high-speed navigation, is that the civilian navigator usually sails established routes. The military navigator must be prepared to navigate in unknown and confined waters, often with poor or restricted data quality [6]. Littoral high speed navigation relies on a consistent methodology to achieve safe and efficient navigation [7], and the design of bridge equipment, layout and Graphical User Interfaces (GUI) must be in compliance with this methodology for successful interaction between the system and the navigator [8]. This underlines the importance of facilitating for systems that support the navigator in managing such demanding tasks.

2.1 e-Navigation

Today's ship bridges are equipped with a well of displays and electronic aids, such as the Electronic Chart Display and Information System (ECDIS). The International Maritime Organization (IMO) has defined the modern and future collection, integration, exchange, presentation and analysis of marine information on board as e-Navigation [9], where the ultimate goal of e-Navigation is to enhance safety and security at sea.

Several studies indicate the close and important relationship between the bridge equipment, the navigators’ attention span and the bridge crews’ use of available resources [10–13]. To improve harmonization and user friendly bridge design, one solution is the Integrated Navigation System (INS). The purpose of the INS is to “enhance the safety of navigation by providing integrated and augmented functions to avoid geographic, traffic and environmental hazards”. Route monitoring is one such task performed by the INS, defined as “continuous surveillance of own ships position in relation to the pre-planned route and the waters” [14]. As such, modern HSCs utilize INS to provide more, and real time, information for the navigator when conducting the passage. Figure 1 shows an example of an INS.

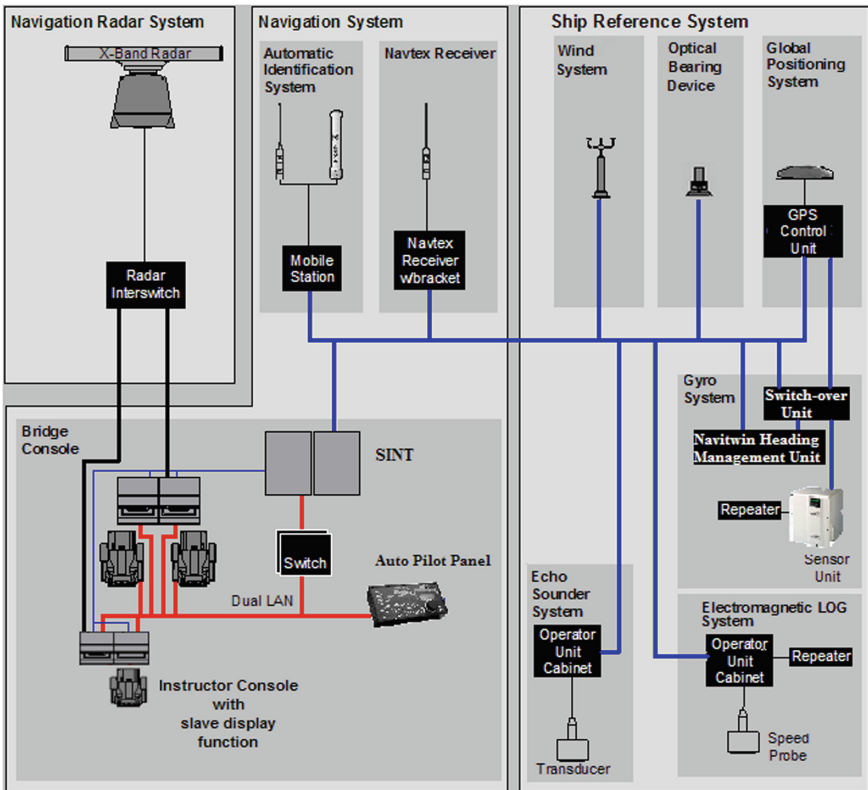


Fig. 1. Example of integrated navigation system (Courtesy of RNoN)

The INS layout in Fig. 1 outlines the complex structure of connecting multiple sensors to facilitate an integrated presentation of navigation information. The data collected is presented for the navigator on Multi-Function Displays (MFDs) in order to conduct navigational tasks.

There is an increased awareness of the need for efficient bridge design in high-speed operations [15]. The e-Navigation initiative has led to guidelines for HCD

emphasizing the importance of including context and purpose in the design process [16]. The International Standardization Organization (ISO) has developed and released a standard for HCD for interactive systems. The standard identifies the importance of an iterative process that must include the end user to evaluate the ergonomics of human-system interaction [17]. This corresponds to other recommendations for designing HSCs based on a user perspective [18]. Reports from the maritime community identifies that several navigators find bridge systems difficult to access, and that they add noise and end up decreasing SA [10]. IMO will rectify some of these problems through its work on e-Navigation, expected to be finalized in 2019. Other initiatives are represented in the ongoing work with the Standard mode (S-mode) in ECDIS. S-mode is expected to contribute to standardisation and to provide detailed requirements for HMI and data presentation [19]. The work and initiatives within the e-Navigation scope underlines the present need for guidelines and standardisation for equipment placement and information presentation on a maritime bridge.

3 Data Collection Process

3.1 Eye Tracking

Eye Tracking is a method for collecting data of the eye's movement [20], and its use has expanded rapidly since the early 1970s. The original drive for eye tracking data was within research on the process of reading, but has later evolved to be used in the maritime industry as well [21, 22].

To improve design, eye tracking data can be analysed to better understand how the operator interacts with the systems [23, 24]. Eye tracking has been used to identify differences in the levels of experience between navigators [22], and to evaluate and improve maritime training [25, 26]. This article presents the development of a HSC route monitor window based on eye tracking data collected in the RNoN [27].

3.2 RNoN Eye Tracking Data Set

The data set is collected in field- and simulator studies using Eye Tracking Glasses (ETGs) [26], during daytime operations on board RNoN Corvettes and in similar conditions in the simulator. The Corvettes (Fig. 2) are capable of speeds exceeding 60 knots, and the navigation team consists of the Officer of the Watch and the Navigator. The navigation system on the Corvettes is delivered by Kongsberg Defence Agency (KDA), and the eye tracking data set was collected from the ECDIS and radar application from Kongsberg Maritime (KM). The ETGs were mounted on the navigator, who is the person responsible for conducting the passage.

The field study was conducted when navigating in littoral waters in the northern parts of Norway. The simulator study was conducted in the Skjold-class bridge simulator at RNoN Navigation Competence Centres' (NCC) Navigation Simulator (Nav-Sim), in a similar area as the field study. Eight navigators from the RNoN attended the trials, with an navigation experience spanning from two to six years, with both male and female participants [26]. The data was collected with the SensoMotoric



Fig. 2. Royal Norwegian Navy Corvette, Skjold-class (Courtesy of RNoN)

Instruments second generation ETGs and the Tobii Pro Glasses 2 [27], and analysed in the supplied and recommended software (BeGaze and the Tobii Pro Glasses Analyzer). 2 h and 57 min of eye tracking data has been processed and analysed in this study.

Eye tracking data in this type of study is unique, but it has still got its' weaknesses. The field data set and the simulator data set are not identical, but the area of operation is similar. There are also differences in the environment when collecting data in a field study versus a simulator study. The light and weather conditions are a challenge, both with regards to the data collection, and also concerning differences in the field study- and the simulator data set. The total amount of participants is eight, of both sexes, and they have a span in experience. The amount of military HSC navigators are limited, and it is difficult to introduce more participants to the data set. The difference between the conduct of the passage concerning sexes is not elaborated. Two different types of ETGs were used in order to collect more experience on different types of ETGs. However, this also hampers the resemblance of the data set. The analysing process of the data is semi-automatic, and is a time consuming task. As a rule of thumb 10 min of data takes 60 min to analyse. There is an uncertainty introduced in the manual task of the analysis due to the ambiguity of the data, and a 10% loss of data is also expected due to weaknesses in the ETG design. Collecting eye tracking data is the easy part and analysing is the challenging part [20].

When analysing eye tracking data, there are several eye tracking metrics and visualization techniques that can be used and applied to better understand the data [28]. One should note that some of the eye tracking data can be notorious ambiguous events. One example is backtracks, which is the specific relationship between two subsequent

saccades where the second goes in the opposite direction of the first [20]. In order to conduct a more thorough analysis of the eye tracking data, it is recommended to use Subject Matter Experts (SMEs), to better understand the meaning of the data.

4 Route Monitor Window

The route monitor window is an important tool for the navigator, and results from the eye tracking data showed a high frequency of use during operation. Figure 3 shows the GUI as it is presented in Kongsberg ECDIS version 3.4.

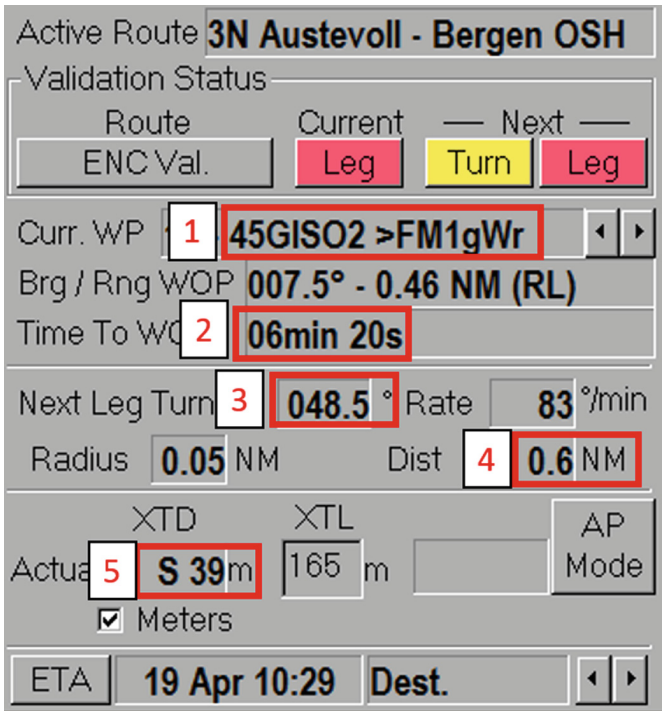


Fig. 3. GUI route monitor window

The route monitor dialog is used to display information about the selected route and to monitor the ships progress along it. The window consists of information about the route and its validation status, together with the current position of the ship and the upcoming information regarding the planned route. It also provides a button to enter the Autopilot (AP) mode, and information about Estimated Time of Arrival (ETA) to the final destination.

Information vital for high-speed navigation is highlighted by red boxes in Fig. 3, consisting of:

1. Information about turning object and next heading mark.
2. Time to Wheel Over Point (when the turn of the ship is to be conducted).
3. The course on the next leg.
4. The distance of the next leg.
5. Cross Track Deviation (XTD) which provides information about the ships actual position compared to the planned route.

The route monitor window is found in the lower right corner of the ECDIS application, and is presented as a KM standard size dialog window as shown in Fig. 4.



Fig. 4. Route monitor window seen from the perspective of the navigator

The distance from the navigator to the route monitor window is approximately 2 metres, and the size of the route monitor window is small, dependent on the size of the MFD. The navigators expressed concern about the accessibility of the information in the route monitor window. To investigate this concern, the scan pattern of the navigator was visualized through analysis of the collected eye tracking data (Fig. 5).

The circles in Fig. 5 represent fixation and the lines represent saccades. Fixation is defined as the state when the eye is remaining still over a defined period on a specific point, and fixation time is defined as how long the eye lingers on a specific fixation. The size of the circle indicates the time period of fixation; the bigger the circle, the longer the fixation. A saccade is defined as the rapid eye motion between two fixations, understood as movement from one fixation to another [20]. When analysing the eye

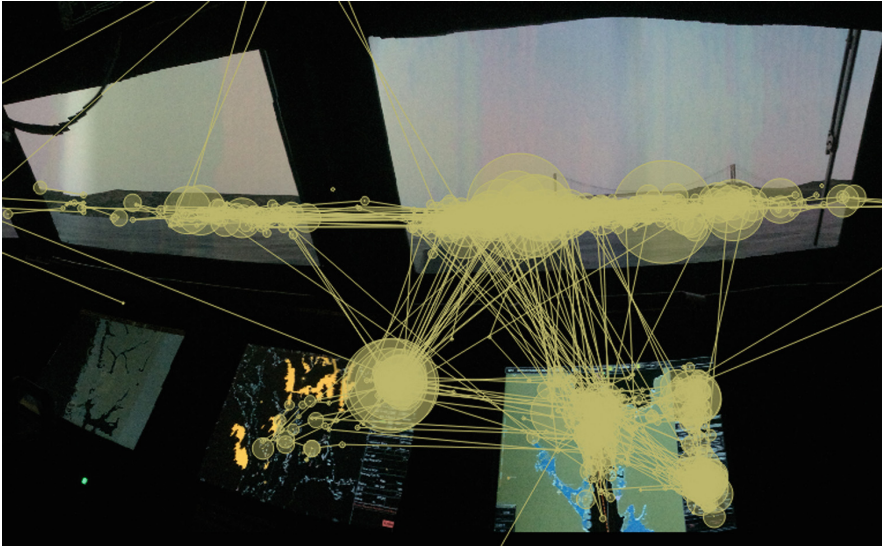


Fig. 5. Scan pattern of the navigator

tracking data together with the visualization techniques, it is identified that the route monitor window GUI is taking too much of the navigators' attention, and thus a HCD process of optimizing this GUI is initiated. This process is laid down in earlier work [28]. The results from the study was combined with RNoN standard operating procedures (SOPs) to manufacture a new HSC route monitor window that is better aligned to the HSC navigator's need.

4.1 Developing a High-Speed Craft Route Monitor Window

In close cooperation with SMEs and the supplier, an iterative process in accordance with IMO's guidelines for software quality assurance and HCD for e-Navigation [16] was started (Fig. 6).

The process is as follows:

1. Identification of challenge in design and HMI [27].
2. Create workgroup with SMEs and supplier to start the iterative HCD process of changing the GUI [16].
 - i. Activity 1: Understand and specify the context of use.
 - ii. Activity 2: Identify the user requirements.
 - iii. Activity 3: Produce and/or develop design solutions to meet user requirements.
 - iv. Activity 4: Evaluate the design against usability criteria;
 - i. Test the new software in a 1:1 simulator [26].
 - v. Activity 5: Maintain operational usability.

This method is illustrated in Fig. 6.

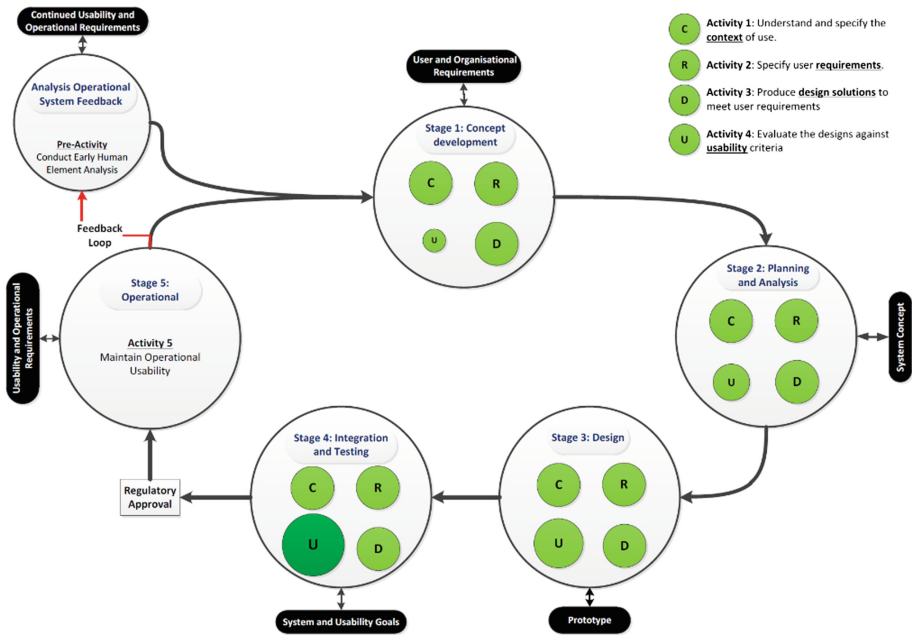


Fig. 6. Overview of HCD process for e-navigation systems (16)

The use of SMEs in a workgroup were essential for all activities leading up to the proposed design, and will be vital for trials and evaluations of the final design.

Activity 1 and 2 resulted in several design suggestions for activity 3, leading up to the conceptual content design of the route monitor window shown in Fig. 7. The supplier followed up the conceptual design with proposing a solution that fits the layout of the existing MFD (Fig. 8). The final proposal from the supplier will be tested later against usability criteria in activity 4.

Activity 1. When identifying the user requirements, it is important to start with the context of use. The context of use is to perform navigation on board a HSC in littoral waters, with the use of modern electronic navigational equipment such as the INS. It involves operations in narrow and open waters and in all types of weather and sea states, and ship movements and vibrations is expected to be high. The ship must also operate in demanding arctic waters, with no daylight during wintertime, which also drives the need for suitable night palettes in the GUI. In addition to this, the navigators’ night vision is essential when conducting the advanced operation of maritime warfighting. Thus, the need for minimum light pollution from the MFDs is crucial.

This context suggests a need for frequent use of the route monitor window, a suggestion identified in a recent maritime usability study [23].

Activity 2. Level of accessibility of information provided in the route monitor window becomes a crucial design parameter. The GUI design must focus on user suitability while at the same time be coherent with RNoN SOPs. The SOPs in this context are the

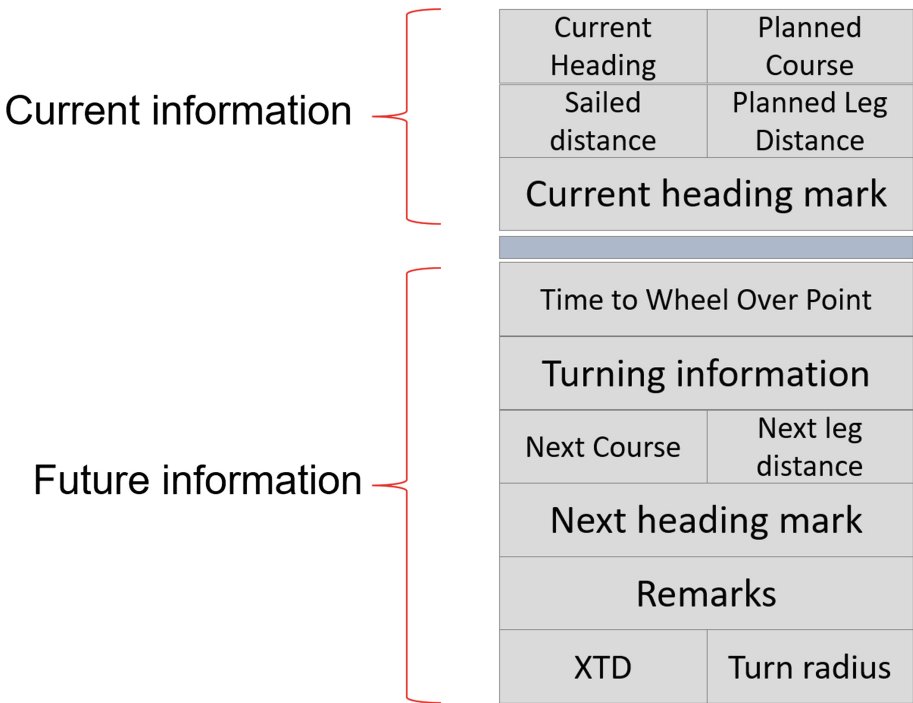


Fig. 7. Conceptual content of HSC route monitor window

rules and regulations for conducting a safe passage, which in the RNoN are known as the phases of navigation, with coinciding voice procedures [7].

The phases of navigation are in place to ensure that the navigator is aware and appreciative of the current and future environment to maximize the capabilities of the HSC. Figure 7 shows the results of Activity 2; a conceptual design of the new route monitor window for presenting the navigator with need-to-know information of the current and future route.

Activity 3. Human engineering design criteria are essential for successful design and solutions for high speed navigation [15, 18]. The conceptual content (Fig. 7) aims to ensure maritime SA for the navigator, and the goal for activity three is to balance user requirements with supplier and bridge equipment capabilities and constraints.

One such constraint is the size of the window, which limits the amount of information available for stacking. The window size is regulated by the design of the Kongsberg K-Bridge INS [29] and must be taken into consideration when designing a new GUI. Optimization of the new HSC route monitor window was made through suitable trade-offs between the supplier design criteria and the end user requirements.

Guidelines and requirements for HCD of display information systems were used to optimize system performance with consideration of inherent human capabilities and limitations as part of the total design trade-off space [30]. Specific considerations were

given to the information architecture, including; the amount of information, density and presentation, text format and pattern coding, information grouping and label orientation.

Current information is presented on top (i.e. “what am I doing now?”) followed by future information (i.e. “what should I do next?”) on the bottom. Related information is grouped in sequences, limited by what kind of information that is necessary and sufficient to maintain maritime SA. This allows the navigators’ scan pattern to flow from top-to-bottom and left-to-right with data presented in a readily usable form [30], avoiding critical data from being obscured by pagination or scrolling.

The coding used in turning - and heading mark information is in accordance with the RNoN SOPs [31].

Based on inputs from RNoN working groups, Activity 3 resulted in a preliminary suggestion for the new GUI from the supplier (KDA), shown in Fig. 8.

Activity 4. The final design suggestion from the supplier will be tested at RNoN NCC NavSim (expected early April 2017). The testing will be performed by RNoN HSC navigators and human factors specialists to ensure that operator interaction requirements are met. Once the design is proven to maintain operational usability for achieving required performance for HSC navigation, the new HSC route monitor window will be implemented in the fleet to foster design standardization.



Fig. 8. HSC route monitor window suggestion from supplier

5 Conclusion

Today and in the future, there will be comprehensive interaction between humans and systems. This article has explained the process of refining and operationalizing a specific HSC route monitor window. Eye tracking data is an efficient Method to identify the level of user interaction with bridge systems, and can be utilized to aid the development of an improved software application. The guidelines for HCD activity 1–5 worked as an iterative process with a particular focus on combining operator requirements with system and human capabilities and limitations. The process resulted in an optimized design of a route monitor window specifically tailored to HSC navigation that will be thoroughly tested for user suitability. The final implementation of the product on-board RNoN ships is expected to minimize the potential human error in the operation and to increase safe navigation.

5.1 Future Work

Test and collect eye tracking data set of the new SW GUI in RNoN NCC NavSim. Implement the improved GUI in the RNoN (activity 5 in the HCD process).

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References

1. McCafferty, D.B., Baker, C.C.: Trending the causes of marine incidents. American Bureau of Shipping (2006)
2. Wingrove, M.: Does ECDIS increase the risk of ship collisions? (2016). http://www.marinemec.com/news/view,does-ecdis-increase-the-risk-of-ship-collisions_42825.htm
3. IMO: International code of safety for high-speed craft. Resolut. MSC **36**, 63 (2000)
4. Aa B: Vision of the fjords (2016). <http://www.braa.no/visionofthefjords/>
5. Gould, K., Røed, B.K., Saus, E.-R., Koefoed, V.F., Bridger, R.S., Moen, B.E.: Effects of navigation method on workload and performance in simulated high-speed ship navigation. *Appl. Ergon.* **40**(1), 103–114 (2008)
6. Glomsvoll, O., Bonenberg, L.K.: GNSS jamming resilience for close to shore navigation in the northern sea. *J. Navig.* **70**, 33–48 (2017). © The Royal Institute of Navigation 2016, doi:[10.1017/S0373463316000473](https://doi.org/10.1017/S0373463316000473)
7. Hareide, O.S., Ostnes, R.: Scan pattern for the maritime navigator. *TransNav – Int. J. Mar. Navig. Saf. Sea Transp.* (2017, in press)
8. Dobbins, T., Hill, J., Brand, T., Thompson, T., McCartan, S.: Standardised information architecture to support the dynamic navigation (DYNAV) standard operating procedure. In: *Human Factors Conference, The Royal Institution of Naval Architects*, p. 7 (2016)
9. IMO: E-navigation IMO (2017). <http://www.imo.org/en/OurWork/safety/navigation/pages/enavigation.aspx>
10. Fagerholt, R.A., Kongsvik, T., Moe, H.K., Solem, A.: Broutforming på hurtigbåter. Kartlegging av problemer med utforming og funksjonalitet på teknisk utstyr på hurtigbåt-bro. Rapport. NTNU Samfunnsforskning AS (2014)

11. Hareide, O.S.: Control of Position Sensor Input to ECDIS on High Speed Craft. University of Nottingham, Nottingham (2013)
12. Hareide, O.S., Ostnes, R.: Comprehension of the eye of the navigator. *Coord. Mag.* **XII**(8), 13–20 (2016)
13. Norris, A.: Integrated Bridge Systems. ECDIS and Positioning, vol. 2. Nautical Institute, London (2010). 215 p.
14. IMO: Resolution MSC.252(83): Adoption of the Revised Performance Standard for Integrated Navigation Systems, p. 49, London (2007)
15. Røed, B.K.: Designing for High-Speed Ships. Norwegian University of Science and Technology, Trondheim (2007)
16. IMO: Guideline on Software Quality Assurance and Human-Centred Design for e-Navigation. In: NCSR (ed.) IMO, London, p. 26 (2016)
17. ISO: 9241-210:2010. Ergonomics of human system interaction-Part 210: Human-centred design for interactive systems (2010)
18. Dobbins, T.: High speed craft design from a human centred perspective. RINA (ed.) RINA, London (2004)
19. NCSR: Development of guidance on the Standardised (or S) Mode of operation of navigation equipment (including plans for a testbed by the Republic of Korea in 2017). In: IMO (ed.) (2016)
20. Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., Van de Weijer, J.: Eye tracking: a comprehensive guide to methods and measures. OUP Oxford (2011)
21. Bjørneseth, F.B., Renganayagalu, S.K., Dunlop, M.D., Homecker, E., Komandur, S. (eds.): Towards an experimental design framework for evaluation of dynamic workload and situational awareness in safety critical maritime settings. In: Proceedings of the 26th Annual BCS Interaction Specialist Group Conference on People and Computers. British Computer Society (2012)
22. Forsman, F., Sjors, A., Dahlman, J., Falkmer, T., Lee, H.C.: Eye tracking during high speed navigation at sea. *J. Transp. Technol.* **02**(03), 8 (2012)
23. Bergstrom, J.R., Schall, A.: Eye Tracking in User Experience Design. Elsevier, Amsterdam (2014)
24. Bjørneseth, F.B., Clarke, L., Dunlop, M., Komandur, S. (eds.): Towards an understanding of operator focus using eye-tracking in safety-critical maritime settings. In: International Conference on Human Factors in Ship Design and Operation (2014)
25. Renganayagalu, S.K., Komandur, S., Rylander, R.: Maritime simulator training: eye-trackers to improve training experience. In: Advances in Human Aspects of Transportation Part III: AHFE Conference, pp. 66–72 (2014)
26. Hareide, O.S., Ostnes, R.: Comparative study of the Skjold-class bridge- and simulator navigation training. *Eur. J. Navig.* **14**(4), 57 (2016)
27. Hareide, O.S., Ostnes, R.: Maritime usability study by analysing eye tracking data. In: International Navigation Conference Proceedings, p. 17 (2016)
28. Hareide, O.S., Ostnes, R., Mjelde, F.V. (eds.): Understanding the Eye of the Navigator. In: European Navigation Conference. Confedent International, Helsinki (2016)
29. Kongsberg: K-Bridge Integrated Navigation System: Kongsberg (2016). [https://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/62F2BB1A93881801C1257CB7003A7687/\\$file/KM_K_Bridge.pdf?OpenElement](https://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/62F2BB1A93881801C1257CB7003A7687/$file/KM_K_Bridge.pdf?OpenElement)
30. DOD US: Design Criteria Standard, Human Engineering, MIL-STD-1472G. In: Defence Do (ed.) (2012)
31. RNoN: SNP 500. In: Centre, N.C. (ed.) Royal Norwegian Naval Academy, Bergen (2012)