NordDesign 2016
August 10 – 12, 2016
Trondheim, Norway

Human-Centred Design in the Maritime Domain

Thomas Porathe

Department of Product Design, Norwegian University of Science and Technology
thomas.porathe@ntnu.no

Abstract

In June 2015, the International Maritime Organization's (IMO) Maritime Safety Committee approved a "Guideline on Software Quality Assurance and Human-Centred Design (HCD) for e-Navigation". This was a tangible result of work done in a number of e-Navigation related EU projects from 2009 and up until today. "e-Navigation" is a concept launched by the IMO to harmonize "the collection, integration, exchange, presentation and analysis of marine information onboard and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment". This new concept has spurred many new projects looking on innovative solutions to accidents in the maritime domain. This paper will summarise some of the new tools developed in a number of e-Navigation related EU projects. However, the focus will be on the maritime HCD methods used.

Keywords: e-Navigation, Human-Centred Design, maritime

1. Introduction

Navigation is one of the world's oldest professions and today 90 percent of all trade is carried by ships. The activity of navigation (*navis* = ship and *agere* =drive) was long surrounded by guild secrecies, but can today be learned from books or vocational schools. Even if the tasks in much remain the same, the actions will differ greatly due to technical development. One hundred years ago offshore positions had to be calculated from the elevation angle of celestial bodies, where as we today can read longitude and latitude off a display (or even better, have the position displayed by an *own ship* symbol integrated into the electronic chart. However, technical development leading to more precise and reliable results has also increased the complexity, which in turn has led to problems of using navigational equipment. The following short case will illustrate this problem.

Figure 1. Left, the planned track of *Ovit* passing right over the Varne Bank (blue area). The picture to the right was taken of the ECDIS by the UK Coast Guard on embarking *Ovit* after the accident.

1.1 The Ovit

In September 2013, the 117 meters long Malta registered chemical tanker *Ovit* ran aground on the Varne Bank in the Dover Strait. The vessel had a draught of 7.5 meters while the sand bank had a depth of less than 5 meters. The bank is well marked with cardinal buoys and a light vessel. Before leaving port, *Ovit* had planned her voyage right across the bank (see Fig. 1, left). How could this happen? Automatic safety devices in the electronic map system are supposed to give alarm when a planned route passes over areas with a water depth less than the set safety depth of the vessel. The accident investigation subsequently showed that the information in the "check-route" window was not understood. This way the first safety barrier was breached. However, there was a second chance to catch the mistake.

The Electronic Chart and Display Information System (ECDIS) system is also constructed so that when a configurable "look-ahead sector" detects a set *safety contour* an alarm is triggered. For *Ovit's* case, the safety contour should have been set at 20 meters. The safety contour was however left at the system default setting 30 meters, and to avoid constantly hearing the alarm, the alarm was disengaged (see Figure 1, right). By leaving the safety contour at 30 meters the bank became almost invisible in the water area coloured blue (non-navigable), thus cancelling also the last, visual, signal of danger.

My point in telling this story is that we here are dealing with a very complex user interface, which has not been understood by the operators who subsequently left it in a default mode effectively cancelling all the sophisticated warnings the system could generate. The Chief Inspector of Marine Accidents of U.K.'s Maritime Accident Investigation Branch (MAIB) wrote in the foreword of this accident investigation report "This is the third grounding investigated by the MAIB where watchkeepers' failure to use an ECDIS properly has been identified as one of the causal factors. As this report is published, there are over 30 manufacturers of ECDIS equipment, each with their own designs of user interface, and little evidence that a common approach is developing." (MAIB, 2014). Writing this in the beginning of June 2016 a headline in a maritime newsletter declare "Australia Finds Detained Bulk Carrier's Crew Was Unable to Operate the Ship's ECDIS" (gCaptain, 2016). Complexity is clearly a problem. Could HCD be a solution?

2. Theory

The rapid technological development during the Second World War lead to an insight that even with the best selection and training, the operation of some of the complex equipment still exceeded the capabilities of the people who had to operate it (Sanders & McCormick, 1992). This lead to the expansion of the science and profession of economics, or human factors and a realisation of a need to fit the equipment to the person instead of the other way around. The wide spread of computers in work places starting in the 70's highlighted the problem of technical complexity versus human abilities. With roots in Scandinavia, Cooperative Design, Participatory Design and finally User-Centred Design turned the searchlight on user involvement in technological development. However, in the maritime domain there was apparently no systematic and sustained tradition of involving users in the design and development of maritime instrumentation (Petersen, 2012). As the satellite based Global Positioning System (GPS) was launched in the 1980s a technical foundation for a new computerised automatic navigation system onboard were laid. Together with electronic nautical charts, the system allowed for automatic plotting of a ships position at the correct passion in the chart. Gone were the tedious and error prone taking of celestial or terrestrial Lines of Position only to make a fix in the chart for a position the ship had already passed. Now you had real-time positioning without any inconvenience. In 1995 the U.S. Coast Guard Research and Development Centre presented a human factors study made on two commercial ECDIS placed on a simulator bridge. They concluded that ECDIS had the potential to improve upon the safety of navigation, compared to conventional procedures. There was also strong evidence that the use of ECDIS increased the accuracy of navigation and reduced the proportion of time spent on navigation, with a corresponding increase in the proportion of time spent on the higher risk collision avoidance task. In addition, ECDIS was shown to improve geographic situational awareness and to reduce navigation errors (Smith et al., 1995). However, as was indicated by the 2013 case of the *Ovit* grounding, the 1995 expectations of the US Coast Guard might not have been fulfilled.

In 2006, the International Maritime Organization (IMO) launched a concept termed *e-Navigation* to "harmonize the collection, integration, exchange, presentation and analysis of marine information onboard and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment" (IMO, 2016). The work with this concept spurred a lot of innovative international cooperation and research within maritime authorities, companies and academic institutions. The users in the maritime domain are an often-conservative guild, heavily regulated by mandatory requirements in detail prescribing equipment and procedures. The challenge now was to develop user-friendly services that gain user acceptance and then to push the results through the regulating authorities. Adding new features to a maybe already over-complex arena with the aspiration of making systems more user-friendly called for new approach. Heavy user involvement was necessary, and also simulator testing of prototypes on an early stage to ensure "professional acceptance". A maritime flavour of HCD (ISO 9241-210) was developed (Petersen, 2012) and elaborated during two e-Navigation HCD workshops in Malmo, Sweden, 2012 and Kingscliff, Australia, 2013. It was later proposed to the IMO by the Australian Maritime Safety Authority and in June 2015 IMO's Maritime Safety Committee approved a "Guideline on Software Quality Assurance and Human-Centred Design for e-Navigation" (see Figure 1). In the following a brief overview of methods used during the different EU-projects are given along with references to more detailed presentations.

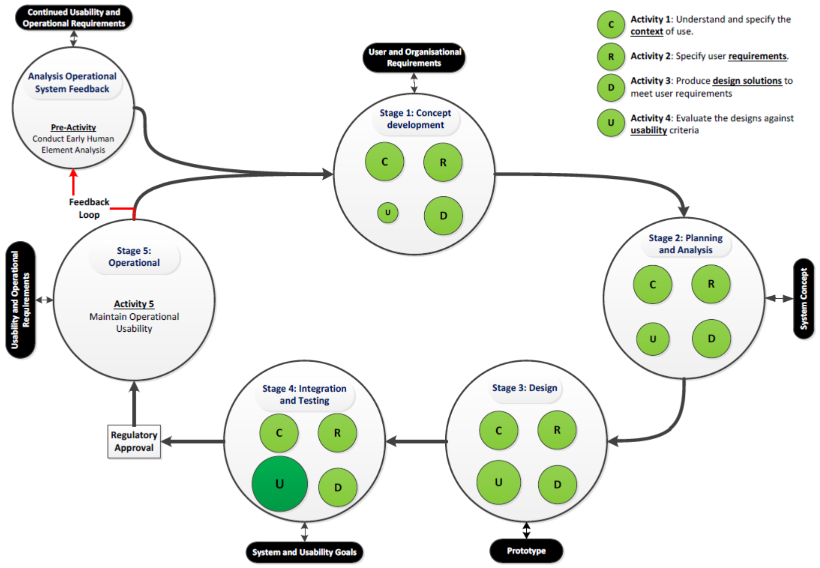

Figure 2. Overview of HCD for e-navigation systems (IMO, 2015)

3. Method

The *Ovit* accident, referred to above, and a great many other accidents described in accident investigation reports, as well as many hundreds of hours of onboard field studies, creates a backdrop against which new ideas for innovative solutions have emerged. In a number of e-Navigation related EU projects from 2009 up until today the HCD process has been used to develop solutions to documented problems. Below are six such solutions shortly presented as an example. All solutions has been prototyped and tested on professional operators, first as low fidelity prototypes and finally implemented in a test-ECDIS either in ship simulators or at sea. These e-Navigation related EU projects were BLAST (2009-2012), EfficienSea (2009-2012), the MONALISA (2010-2013), the ACCSEAS (2012-2015), and the MONALISA 2.0 (2013-2015).

3.1 Innovative e-Navigation solutions

3.1.1. Strategic route exchange

By regulations from the IMO, every ship leaving port is mandated to have a voyage plan. This plan is clicked out in the ECDIS, then the checks and alarms mentioned in the *Ovit* case take place. However, this voyage plan is not shared with anybody and is solely kept onbord the vessel. What about if this plan was shared with the surrounding world? Then a vessel traffic centre, or even a helpful passing vessel, could call up and warn of an improper course or a potential danger situation. There would be more eyes that could spot mistakes. Ships could send their voyage plans to a coordination centre ahead of departure. For vessels predicted to be at the same place at the same time, a small speed change could be the difference between a normal journey and a close quarter’s situation that might develop into a collision. This idea termed “strategic route exchange” The question was if this could be done in an intuitive and user-friendly way without adding to the technical complexity and workload on the bridge? (Porathe & Brodje, 2015). A screen dump from the prototype tested is shown in Figure 3.

Figure 3. Example from the strategic route exchange prototype. The navigator can here send a planned route to a coordination centre.

3.1.2. Tactical route exchange.

The planned routes of commercial vessels are commonly surrounded by some secrecy for business reasons. Therefor they cannot be openly shared, only the coordination centre will see them. However, if so, one of the major points of sharing intentions is lost. But, if ships would transmit only a few, “tactical” waypoints ahead of time (say 60-90 minutes) intentions valuable for decision making and collision avoidance could be communicated to other ships in the vicinity. This process would be different and much simpler than the strategic route coordination (Porathe et al., 2015). A screen dump from the prototype tested is shown in Figure 4.

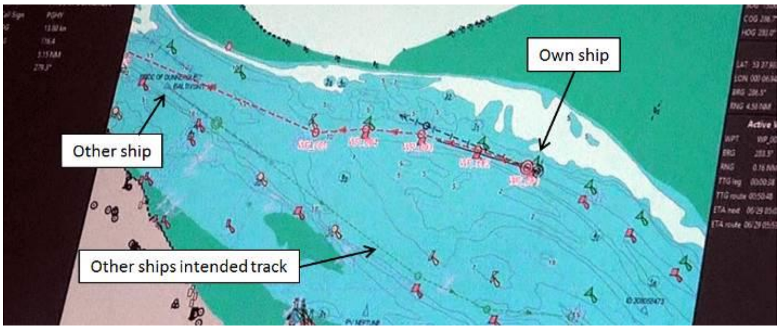

Figure 4. By right-clicking on another ship and selecting “show intended track” other ship’s intentions can be visualised.

Figure 5. The yellow segment has been sent to the ship from the VTS and recommends using the Northern channel.

3.1.3. Suggested routes

Another way of using route sharing would be “route suggestions”. In areas with many ships, Vessel Traffic Services (VTS) are established. These VTSs often intervene when they see ships heading for danger. The procedure is then to call the ship on radio and suggest another course. Noisy radio communication and maybe language difficulties are error prune and communication could be facilitated by letting the VTS send a route segment straight to the vessel's ECDIS screen, where the bridge officer then could agree or discard the suggestion. Thus moving common route suggestions from the verbal to the graphical domain (Brodje et al., 2015). A screen dump from the prototype tested is shown in Figure 5.

3.1.4. Search patterns for search and rescue operation

When ships participate in Search and Rescue (SAR) operations at sea, the search pattern for each ship is decided by the rescue operations centre and verbally communicated to the vessel using radio. This communication will include several positions consisting of a longitude and a latitude with multiple number strings, taking time and risking miscommunication. The same mechanism that allows for sharing route intentions and suggestions would be used for communicating search patterns to SAR vessels (Porathe, 2012). A screen dump from the prototype tested is shown in Figure 6.

Figure 6. Search patterns for this rescue boat is transmitted directly to the onboard chart system.

3.1.5. Dynamic NoGo areas

The final example here is the dynamic NoGo areas. Depth information is conveyed in the nautical chart based on a "chart datum" to which soundings are referenced. However, the actual navigable area depends on several factors like the ship's draught and the tidal situation. To be able to figure out a ships "NoGo areas" (where the water is too shallow) the mariner need to apply quite some cumbersome mental arithmetic. However, this calculation can easily be done by the navigation system given the right format of bathymetrical data. Unfortunately, todays electronic charts are based on an old paper chart data model, but with a new data model, Dynamic NoGo areas could be presented to the marines in real time showing were he could sail and where not, and even forecast such areas ahead of time along his planned route (Porathe & Billeso, 2015). A screen dump from the prototype tested is shown in Figure 9.

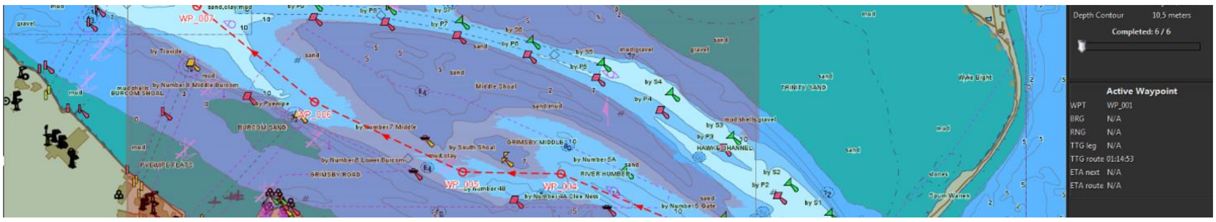

Figure 9. Own ship's planned track is shown as the red dashed line. NoGo polygons for the area within the rectangle drawn on the screen are displayed in a transparent red coloured layered on top of the nautical chart.

3.2 HCD methods used

It is clearly stated by the IMO initiative that e-Navigation should be user and not technology driven. Solutions to concrete problems can come from any individuals or groups, from within the profession or from the design environment. It is important that designers attempting to design for the maritime domain are “marinated” and know the context well. A common mistake encountered by the author is that designers do not thoroughly understand the simple that ships roll in bad weather and that bridge officers need handles to hang on to and thus may only have one hand to work with. “One hand for the ship and one for yourself” is an old proverb originating from the age of sailing ships (personal communication handed down from my great grandfather). Once a suggested solution is proposed, it has to be tested to make sure it is usable and does not create other problems. The most cost effective way is to do this at a very early stage, on low fidelity prototypes that are being tested with the real uses. In the following, examples of HCD methods used are presented.

3.2.1. Interviews and focus groups

One of the simplest and easiest approaches is to meet the users face to face. This can be done on neutral ground in interviews or focus groups. Such a meeting should have a concrete topic or theme of discussion and it can be useful to have an expert or a user introduce the topic and provide context. The objective can for instance be to identify problems, or capture user requirements, or just brainstorming to find solutions to problems. In later stages presentations of ”design provocations” can be useful. For an example see Porathe (2012).

3.2.2. Contextual inquiries/field studies

Working in a maritime context means that the researcher has to go to sea and be present within the context of research. The researcher needs to spend time onboard. Much of the knowledge and procedures are “tacit,” cannot be verbalized but needs to be demonstrated and detected in context. Also, with expertise, the human factors researcher can infer cognitive bottlenecks and high workload situations that the user might not think of, being used to the familiar situation. Also many new ideas might come up based on a discussion in the particular situation. For an example see Porathe (2012).

3.2.3. Usability tests in simulator

A bridge simulator is a piece of laboratory hardware and software that simulates a ship’s behavior from the vantage point of its bridge. Often it consists of a mock-up bridge (a more or less realistic bridge interior with consoles, screens, instruments and windows to the outer world) but often also a visualization, i.e. the egocentric 3D view of the surrounding world with ships, islands and ports projected on screens outside the windows. One important aspect of the simulator is that it realistically simulates a ship’s behavior in different environments, this in turn paving the way for the other important aspect, that it allows the user to become immersed in the situation. Simulation thus may more or less realistically condition the user’s frame of mind in the context of the real-world environment, all without the costs and possible dangers associated with using a real ship. From an methods point of view it also allowes proper experiments to be conducted, as a situation can be replicated precisely again and again while varying only one variable. For an example see Porathe, deVries, Prison (2013).

3.2.4. System simulations

A system simulation is a complex simulation involving more than one live ship and shore-based services. The purpose of a system simulation is to make observations of human behavior and cooperation in a complex maritime environment. These observations will then hopefully shed some light on interaction in larger social and technical networks. The goal is to analyze how people, involved in the navigation of ships, work and communicate For an example see Lutzhoft, et al., (2010).

3.2.5. Sea tests

At the end of a development process it is necessary to let new technological inventions meet the real context under safe forms. This often means that new equipment or processes cannot be actively used in navigation, due to regulations, or must be tested elsewhere on the bridge. For an example see Porathe, (2012).

3.2.6. Surveys

In early design, proposing and testing innovative solutions that are new to the maritime domain, resistance to change are often explicit. This was often the case in early interviews and focus groups when a concept was only probed verbally. However, when working prototypes was tested in a simulator or real environment reactions generally was different. We therefore developed a subjective “Professional Acceptance Rating Scale”. This was used both in the European studies as well as in a cross-cultural study made with Korean mariners. For an example see Porathe, Borup, et al. (2014).

4. Results and discussion

The detailed results for the studies mentioned above has been presented in the papers referred to in each case, and this paper will only give a short general overview of the findings from the projects mentioned. The focus here will instead be on the results from the Human Centred Design point of view.

Findings from the different prototype tests were reported back to the respective projects and disseminated to the various stakeholder organizations involved in the e-Navigation process and ultimately to the IMO.

The new “Professional Acceptance Rating Scale” was developed for subjective rating of what we termed “professional acceptance”. The reason for this was that the maritime domain was considered conservative and reluctant to accept new tools and processes. We felt it could be important to have a subjective, but straight answer on the question if the test participant would accept using the tool/process in a professional capacity.

For instance, the findings from the prototype tests with strategic route exchange in the two MONALISA projects were generally positive (e.g. Porathe & Brodje, 2015)). They showed good professional acceptance as scored on the Professional Acceptance Rating Scale. In addition, the findings from the prototype tests with the intended route feature in the EfficienSea and ACCSEAS projects suggested that it serves its purpose well. Early concerns raised regarding possible risks if ships did not follow their intended routes (e.g. in case of an overtaking) was revoked in the later study. Experienced officers and pilots considered it beneficial to know other ships intentions even if they deviated from the intended route. The professional acceptance rating used in the last studies showed good acceptance scores. Most participants, both younger and older were more or less positive to the route exchange concept. All participants agreed that the final decision should to stay with the captain onboard.

In the e-Navigation research and development untaken during the different EU-projects 2009-2015 the maritime HCD methodology has been used, and it was finally agreed upon as a guideline in the IMO in 2015.

5. Conclusions

In some recent project, a Human-Centred Design process has been used to develop new innovative tools for the maritime domain. Previously bridge equipment has been lacking in usability as was illustrated by the *Ovit* case. In a number of EU projects HCD was used to develop prototype tools which was tested on users with good results. These results were fed into the IMO who in 2015 agreed to recommend that HCD should henceforward be used in development of new navigation equipment.

References

ACCSEAS (2013-2015). http://www.accseas.eu/ [acc. 2016-06-01].

Blanding, H.C. (1987). Automation of ships and the human factor. In: SNAME Ship Technology and Research Symposium, Philadelphia.

BLAST (2009-2012). http://www.blast-project.eu/ [acc. 2016-06-01].

Brodje, A. Weber, R., Camre, D., Borup, O. & Porathe, T. (2015). Supporting Voice Communication Between Navigator and VTS by Visual Solutions – Exploring the Use of the "Route Suggestion" Functionality within VTS. In A. Weintrit, & T. Neumann (Eds.) Information, Communication and Environment: Marine Navigation and Safety of Sea Transportation, London: CRC Press, 267-273.

Cotter, C. (1971). A Brief History of Sailing Directions. *Journal of Navigation*, 36, 249-261.

EfficienSea (2009-2012). http://efficiensea.eu/ [acc. 2016-06-01].

EfficienSea 2 (2015-2018). http://efficiensea2.org/ [acc. 2016-06-01].

gCaptain (2016). https://gcaptain.com/australia-finds-detained-bulk-carriers-crew-was-unable-to-operate-the-ships-ecdis/?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+Gcaptain+%28gCaptain.com%29 [acc. 2016-06-01].

IMO (2016) http://www.imo.org/en/OurWork/Safety/Navigation/Pages/eNavigation.aspx [acc. 2016-06-01].

IMO. (1997) Resolution A.850(20). http://www.imo.org/en/OurWork/HumanElement/VisionPrinciplesGoals/Documents/850(20).pdf [acc. 2016-06-01].

IMO (2015). Guideline on quality software assurance and human centred design for e-navigation. MSC. 1/Circ.1512, 13 July 2015.

Lutzhoft, M., Porathe, T., Jenvald, J. & Dahlman, J. (2010). System simulations for safety. In O.Turans, J. Bos, J. Stark & J. L. Colwell (Eds.) Proceedings of the International Conference on Human Performance at Sea 2010. Glasgow: University of Strathclyde.

MAIB (Maritime Accident Investigation Branch). (2014). *Report on the investigation of the grounding of Ovit in the Dover Strait on 18 September 2013*. Marine Accident Investigation Branch, Southampton, UK.

MONALISA (2010-2013). http://www.sjofartsverket.se/monalisa [acc. 2016-06-01].

MONALISA 2.0 (2013-2015). http://www.sjofartsverket.se/en/MonaLisa/MONALISA-20/, and http://stmvalidation.eu/ [acc. 2016-06-01].

Reason, J. (1990). Human Error. Cambridge University Press, Cambridge

Rouse, W.B., Rouse, S.H. (1983). Analysis and classification of human error. IEEE Trans. Syst. Man Cybern. SMC-13, 539–554.

Sanders, M. S. & McCormick, E. J. (1992). Human Factors in Engineering and Design (7th ed.) McGraw-Hill Inc.

Sandquist, T.F. (1992). Human factors in maritime applications: a new opportunity for multi-modal transportation research. In: Human Factors 36th Annual Meeting.

Petersen, E. S. (2012). Engineering Usability. Dissertation, Dep. of Shipping and Marine Technology, Chalmers University of Technology, Gothenburg, Sweden.

Porathe, T. (2012). Transmitting intended and suggested routes in ship operations: cognitive off-loading by placing knowledge in the world. Work 41 (2012) 4873-4878.

Porathe, T., de Vries, L., & Prison, J. (2013). Ship voyage plan coordination in the MONALISA project: user tests of a prototype ship traffic management system. In De Waard, et al. (Eds.) Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2013 Annual Conference.

Porathe, T. & Billeso, M. (2015). Human Factors in e-Navigation: a study of Dynamic NoGo Area Visualization in Electronic Nautical Charts. *Proceedings of International Conference of Advanced Intelligent Maritime Safety and Technology, A-MAST 2015*. Korea Advanced Institute for Maritime Safety and Technology, MMU and Korea Research Institute of Ships and Ocean Engineering (KRISO).

Porathe, T., Borup, O., Jeong, J. S., Park, J. H., Andersen Camre, D., & Brodje, A. (2014). Ship traffic management route exchange: acceptance in Korea and Sweden, a cross cultural study. *Proceedings of the International Symposium Information on Ships, ISIS 2014*. Hamburg 4-5 September 2014. pp 64-79.

Porathe, T. & Brodje, A. (2015). Human Factor Aspects in Sea Traffic Management. *Proceedings of the 14th International Conference on Computer Applications and Information Technology in the Maritime Industries (COMPIT '15)*, V. Bertram (Ed.) Hamburg, Technische Universität Hamburg- Harburg.

Porathe, T., Brodje, A., Weber, R., Camre, D. & Borup, O. (2015). Supporting Situation Awareness on the bridge: testing route exchange in a practical e-Navigation study. In A. Weintrit, & T. Neumann (Eds.) *Information, Communication and Environment: Marine Navigation and Safety of Sea Transportation*, London: CRC Press, 85-92.

Rothblum, A.M.: Human Error and Marine Safety, USCG. (n.d.). http://bowles-langley.com/wp-content/files_mf/humanerrorandmarinesafety26.pdf [acc. 2016-06-01].

Smith, M. W., Akerstrom-Hoffman, R. A., Pizzariello, C. M., Siegel, S. I., Schreiber, T. E., & Gonin, I. M. (1995). Human Factors Evaluation of Electronic Chart Display and Information Systems (ECDIS): United States Cost Guard Research and Development Center.