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Testing Proof of Concept of a Web-Based Ship Manoeuvring Training Tool in the Classroom

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Abstract - **Currently, real-time ship manoeuvring simulations are confined to static environments e.g., desktop/full-mission bridge simulators. *Seaman Online™* is a novel web-based ship manoeuvring training tool allowing students and professional mariners to practice manoeuvres in ports and confined waters from their personal computers. This paper describes the tool's first-time implementation in a Master Mariner university programme. The students were asked to complete a post-questionnaire regarding their use experience and the results were discussed between the course instructors and the tool-providing organization at two debriefings. The aim was to obtain feedback about (a) the usefulness of the tool in manoeuvring training; (b) further design improvements and usability; and (c) how to best incorporate it into the programme curriculum in coming academic years for improved user experience. Results revealed usability and maturity issues and the need for further guidance on simulation-based training objectives and limitations. Overall, the tool's usefulness and potential in individual manoeuvring training were demonstrated.**

Keywords
Navigation, manoeuvring, e-learning, simulation, usability.

INTRODUCTION

The maritime sector is a complex, dynamic and safety-critical domain (Costa, 2018; da Conceição, Dahlman, & Navarro, 2017; Grech, Horberry, & Koester, 2008; Lützhöft & Vu, 2018; Manuel, 2011). Ship manoeuvring, in particular, may be defined as a complex physics problem with a large number of parameters and forces involved (Baudu, 2014). Although these parameters and forces and their effects may be mathematically described, mariners will hardly have the opportunity to do any calculations during manoeuvring operations and will thus need to rely on their understanding, knowledge and experience of ship handling. Whilst lectures and text books provide the theoretical background, simulation exercises will, to a certain extent, give the trainees first-hand practical training in ship manoeuvring.

Simulation is an educational – or recreational – technique that allows mimicking all or part of a real-life activity in a controlled environment, at a low to high fidelity level (i.e., how well the simulation replicates reality), without the risks that a real-life setting would entail (Beaubien & Baker, 2004; Maran & Glavin, 2003). The use of simulators (i.e., artefacts/facilities that embody the simulation) in the training and assessment of mariners is endorsed by the International Maritime Organization's (IMO) Standard of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, 2017). Nautical simulation-based training helps to learn ships' reactions and behaviours (Baldauf & Benedict, 2018) and allows for testing safety-critical activities in a risk-free (Beaubien & Baker, 2004; Maran & Glavin, 2003; Sellberg, 2018) and more cost-effective environment (Sellberg, 2018). Another advantage of simulation-based training is the possibility for the instructors to tailor exercises to specific situations and learning objectives (Maran & Glavin, 2003; Sellberg, 2018) and/or to the experience or performance of the trainees (Sellberg, 2018).

There are different simulation technologies and at different levels of fidelity. They can contribute to developing technical and/or managerial, communication or teamwork skills differently (Maran & Glavin, 2003). Some simulation technologies replicate only part of a task and/or have simplified representations of a real environment. These are normally considered of low fidelity (e.g., desktop-based simulations). Other simulation technologies duplicate a whole environment where team situations can also be tested, and/or replicate a real-life environment more realistically, and hence are considered of high fidelity (e.g., a full-mission ship bridge simulator). The degree of fidelity, however, does not determine the effectiveness or success of the learning outcomes (Hamstra,

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Brydges, Hatala, Zendejas, & Cook, 2014). The outcomes depend on the learning objectives, the competencies that are to be developed, and how simulation can be used for these purposes (Dahlström, Dekker, van Winsen, & Nyce, 2009; Maran & Glavin, 2003; Sellberg, 2018).

Ship Manoeuvring Training Tool Seaman Online™

Currently, virtually all real-time ship manoeuvring simulations are confined to static environments such as desktop or full-mission (3D) simulators. *Seaman Online™* (see Figure 1) is a novel ship manoeuvring training tool that offers high availability and flexibility by being web-based and requiring solely a personal computer and an internet connection for both students and professional mariners to individually have access to simulation-based training and safely practice manoeuvres in ports and confined waters.

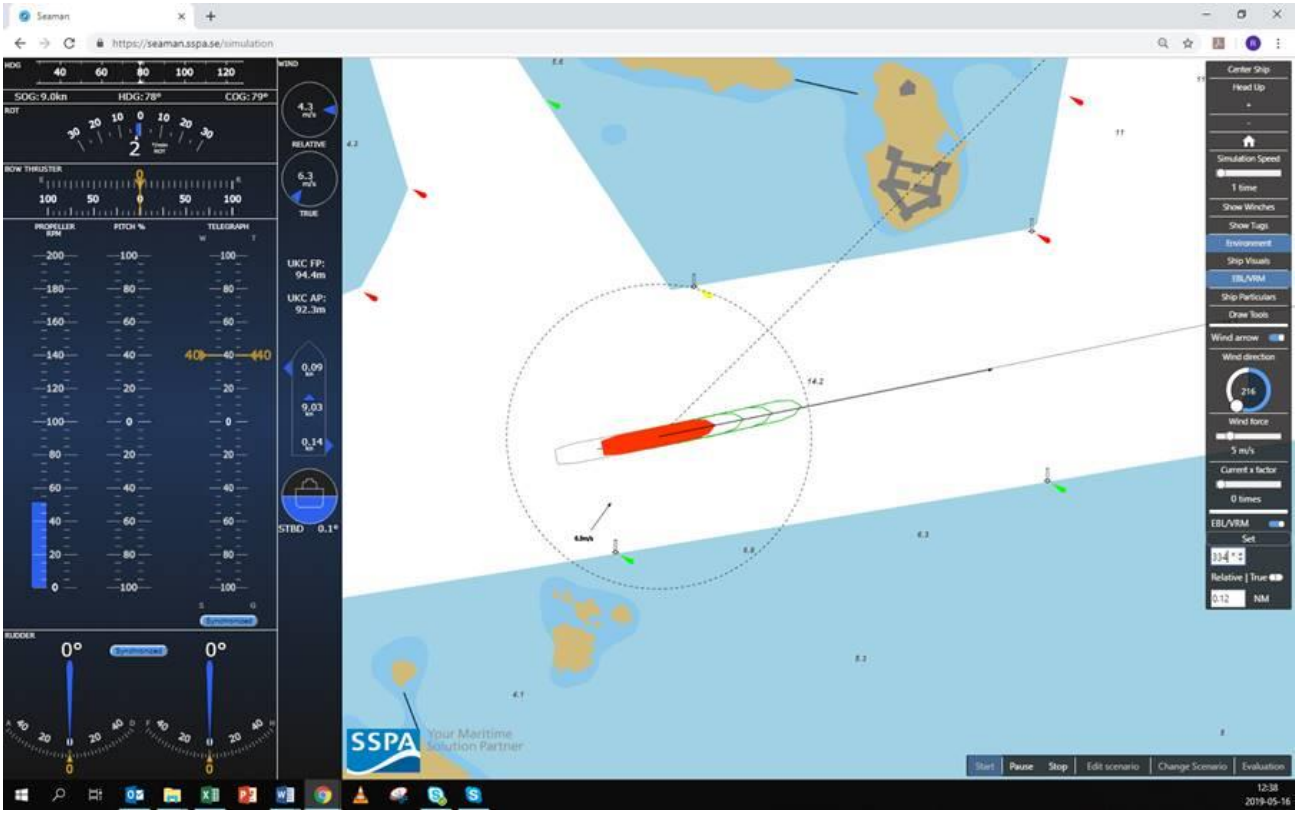

Figure 1. Example of the simulation web page from Seaman Online™.

Seaman Online™ is an extension of an existing simulation software at SSPA Sweden AB which has been used as the company's core numerical simulation software for around four decades in a number of different capacities, such as full-mission bridge simulation, fast-time simulations, Monte-Carlo simulations, among others. The software is based on the company's extensive knowledge of hydrodynamics and other operational aspects associated with ship manoeuvring. Other extensions of this core software are, for instance, the 2D and 3D bridge visualizations and the conning display used at the organization's full-mission bridge simulator, for training and testing purposes. The interface of the conning display was redesigned in 2015 in the context of a European Commission project, CyClaDes [www.cyclades-project.eu], through a human-centred design process where user involvement was sought for design input to create a more usable interface (Costa, Holder, & MacKinnon, 2017). Seaman Online™ is the most recent extension of SSPA's existing core simulation software and was also influenced by the work done during this human-centred design process and by further user feedback during other full-mission simulation projects.

The purpose of developing Seaman Online™ was to increase the availability of a ship manoeuvring training tool through a web browser, to allow for bulk training of students taking e.g., a course in vessel manoeuvring, or of professional bridge officers or pilots. Each simulation on Seaman Online™ can be customized for specific situations and learning objectives. Generally, the tool involves four modules:

- Ship dynamics modelling (how ships react under certain forces, e.g., shallow water effects, weather and currents, engine, mooring and tugboat dynamics).

- 2D birds-eye visualization of the Electronic Navigational Chart (ENC) adhering to the International Hydrographic Organization's (IHO) S-52 standard, and of visual parameters such as wind arrows and speed vectors.
- Analysis (an evaluation page of the simulation results, including qualitative and quantitative feedback to users about their manoeuvring exercise performance and ship dynamics. A student can flag her/his evaluation page to give the instructors access to the results).
- Administration (an administration portal where the instructor can design new training scenarios based on the available ports and ships, see the enlisted students and groups, assign specified scenarios/exercises to specific students/groups, receive students' evaluation pages and comments, and submit feedback to them).

Usability and User Experience

The employment of human-centred design principles, as mentioned earlier, helps to ensure that a product becomes more usable to the target user group (Grech et al., 2008; ISO, 2010; Maguire, 2001) in achieving intended tasks and goals with efficiency, satisfaction and effectiveness (ISO, 2002, 2010). A usable product can thus promote productivity and reduce the propensity for errors (Maguire, 2001).

The practice of usability evaluation methods is about having users/subject-matter experts inspect the usability-related aspects of a product design and user interface (Hornbæk, 2006; Jordan, 1998; Lewis, 2014; Nielsen & Mack, 1994), supporting the human-centred design principles (Jordan, 1998; Maguire, 2001) and capturing user experience and perceptions (ISO, 2010). A lack of user participation/representation might result in lower user acceptance (Norman, 2013). Usability evaluations can resort to a number of quantitative and/or qualitative methods, from questionnaires to interviews, to performance-related measurements, etc. (ISO, 2002).

Study Aim

In order to assess proof of concept and use experience of Seaman Online™ as part of the resources of a university course, its first-time implementation in this context was followed up by an online questionnaire for the students. The tool implementation and questionnaire results were then discussed among the course instructors involved and the members of the tool-providing organization (the tool developer and a researcher) at two debriefing sessions. The aim was to obtain (a) feedback about the usefulness of the tool in manoeuvring training; (b) design feedback for its further improvement and usability; and (c) feedback on how to best incorporate it into the programme curriculum in coming academic years for improved user experience.

METHOD

SSPA Sweden AB and Chalmers University of Technology are collaborating organizations in Gothenburg, Sweden. The division of Maritime Studies at Chalmers has for over a decade been using an older version of SSPA's simulation software on stationary desktop computers in their desktop simulation room for ship manoeuvring education purposes. Once SSPA began to ideate Seaman Online™, SSPA and the maritime simulation instructors at Chalmers came into contact to implement it as an additional resource and a replacement of the older software for student education in a course within the Master Mariner programme.

After the first version of Seaman Online™, Chalmers course instructors submitted to SSPA design requests that would better fit their needs and the course, helping SSPA to generically refine the design before the first-time implementation at the institution.

Tool Implementation

Context

The course in which Seaman Online™ was made available to the students as a resource was the compulsory "*Ship handling and navigation in confined waters*" course, which is part of the third-year curriculum of the four-year bachelor's programme for Master Mariner at Chalmers University of Technology. The course ran from January-March 2019. The students were provided with the tool through a university-purchased license and individual student accounts, during the whole duration of the course. Besides access to this tool, the students had compulsory instructor-led exercises in navigating in confined waters, anchoring and berthing manoeuvres using both Chalmers' desktop simulators (a room with five desktop stations) and bridge simulators (five part-mission bridge rooms).

The scope of the course is to gain knowledge and skills in the following main topics:

- Applied hydrodynamics (IMO manoeuvre tests, shallow water effects, ship interactions, etc.).
- Manoeuvring characteristics of different ships including the controllable, semi-controllable and uncontrollable forces involved in ship handling.
- Planning, executing and monitoring passages in confined waters such as archipelagos (blind

pilotage techniques on radar, controlled turns, etc.).

- Manoeuvring large ships with and without the use of tugboats.

Sample

The class was comprised of 32 students, of which 3 were female, and ages ranged from 21-39 years old. The students had at least five months (approx.) of prior experience onboard vessels as cadets by this time in the programme (which does not necessarily imply any experience in manoeuvring a ship at this stage). Out of the 32 students, 23 answered the voluntary questionnaire. No measurable feedback was collected from the remainder of the students.

There were several instructors involved in this course, of which two used the tool with the students (including the course coordinator). The instructors were experienced master mariners.

Familiarization and Support

For familiarization, the course coordinator produced two video tutorials for the students to watch as preparation before using Seaman Online™ in four course assignments. The first video demonstrated the basic principles of the tool's simulations and the second video demonstrated tool's simulations with the use of tugboats (see Figure 2 and Figure 3 as examples). The tool was also shortly introduced during a lecture (going through the same content as in the video tutorials), and the course coordinator also pre-programmed a special familiarization scenario within the tool. For tool support throughout the course, the students could pose questions and/or report issues to the instructors, who would get direct support from the tool developer when needed.

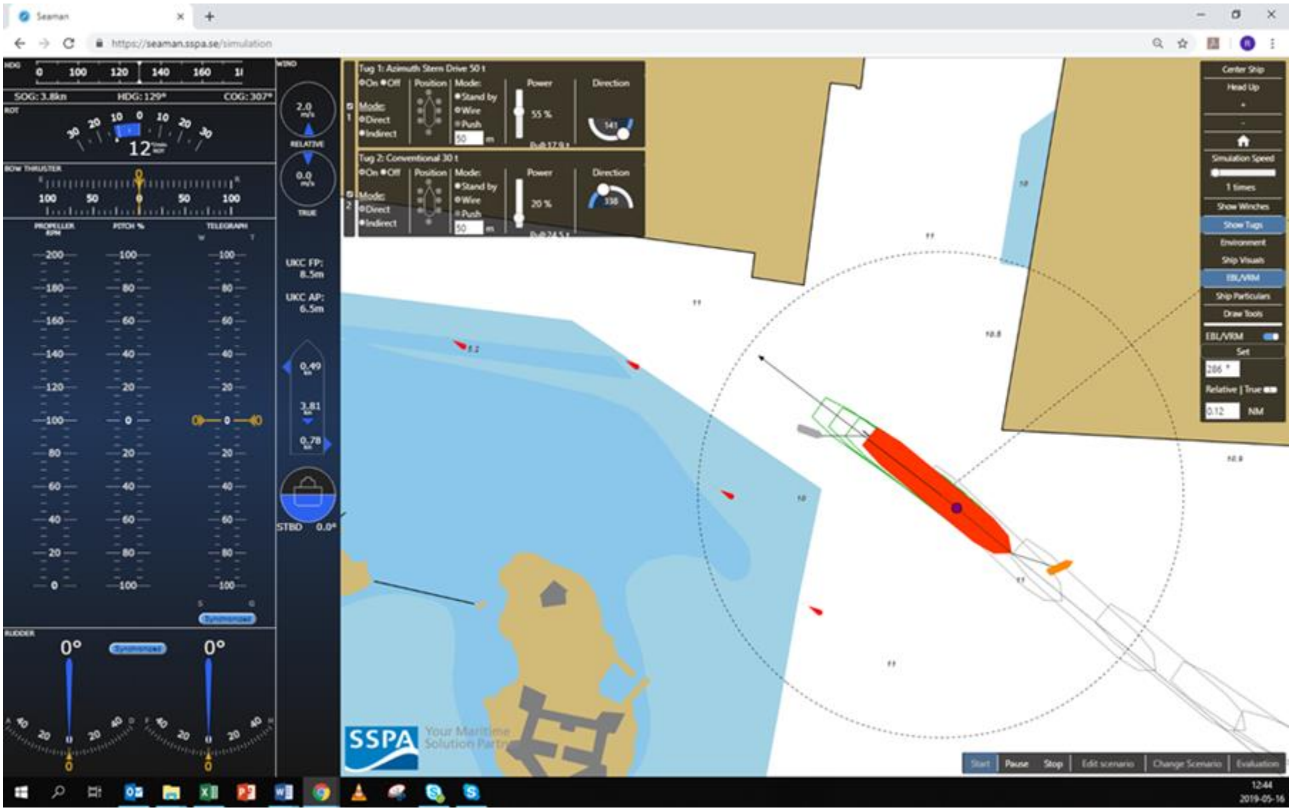

Figure 2. Example figure from the second familiarization video tutorial, demonstration with tugboat assistance.

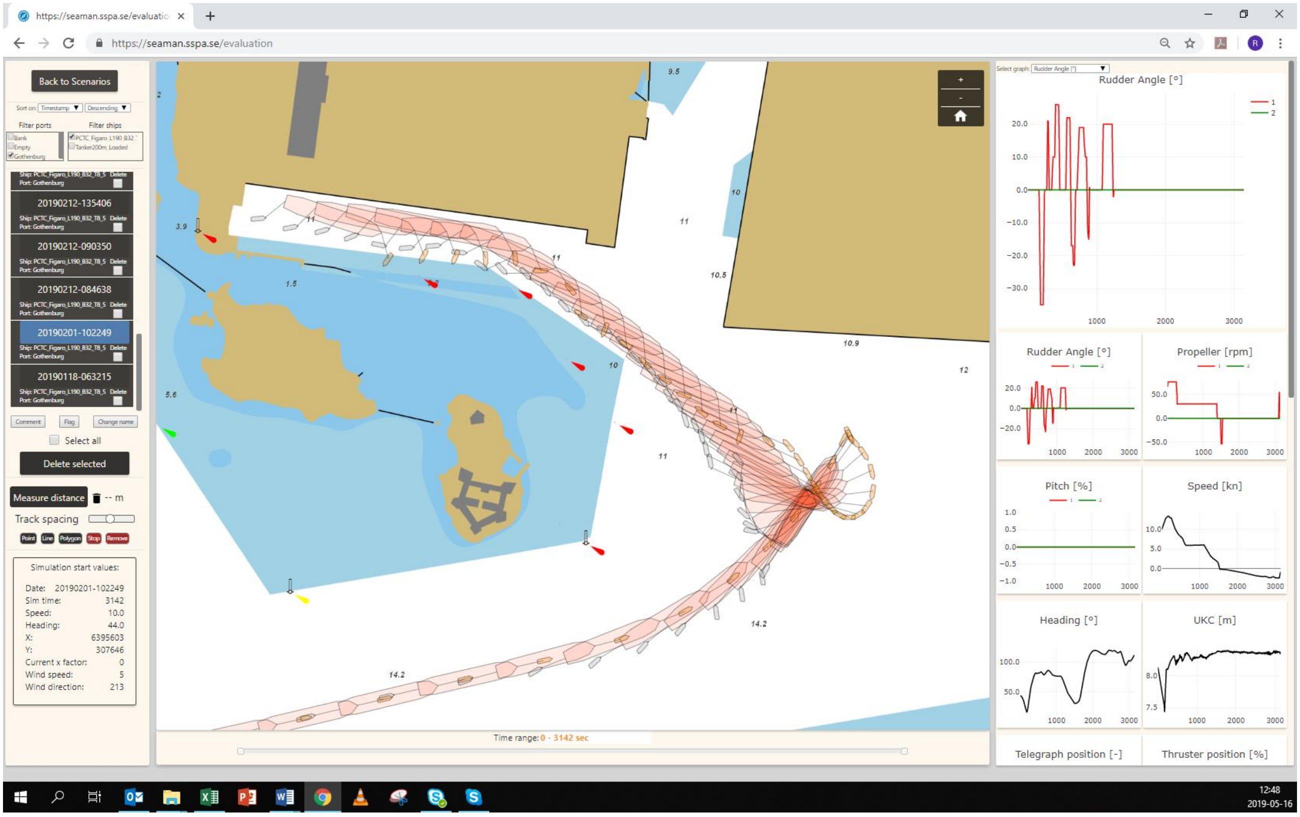

Figure 3. Example figure from the second familiarization video tutorial, evaluation page.

Instructed Assignments

Following the established course syllabus and educational goals, the course coordinator pre-programmed into the tool a number of exercise scenarios for the students to perform specific manoeuvres (one familiarization scenario (without tugboats), four exercises that the students were instructed to complete within the course, and an additional manoeuvre training scenario (with the possibility to connect to tugboats)). For each of the four exercises, the students received directives (description and goals) from the instructors (see Table 1).

Table 1. List of instructed assignments pre-programmed into Seaman Online™ for the students to perform specific manoeuvres.

Assignment	Description/Goals
Assignment 1 (IMO turning circle test with a tanker, in deep and in shallow waters)	The goal of this exercise was to understand the difference in the turning ability of a ship in deep and in shallow waters, and to assess whether the vessel fulfilled the IMO criteria regarding the turning tests for both cases.
Assignment 2 (ship interactions – meeting, overtaking; squat and bank effects)	The goal of this exercise was to experience and appreciate the effect of interaction and its forces on a ship's behaviour, and to practice controlling a ship under interaction effects.
Assignment 3 (berthing a PCTC)	The goal of this exercise was to safely manoeuvre the vessel to berth 712 Älvsborgshamnen without the use of tugboats. (*this exercise was assigned with the intent of preparing the students for the later similar exercise in the bridge simulators*)
Assignment 4 (berthing a PCTC with the use of tugboats)	The goal of this exercise was to understand (a) the capability and limitations of tugboats using "indirect mode" assistance, (b) the forces on the tug rope using "indirect mode", and (c) the difference between "static bollard pull" and "dynamic bollard pull", as well as to be able to use different techniques for port tugboat towing and to safely manoeuvre the PCTC vessel from Gäveskär to berth 712 Älvsborgshamnen.

After performing each exercise on Seaman Online™, the logged data from the run was graphically presented on the evaluation page. The students were asked by the instructors to reflect on relevant information on their evaluation pages and write a short analysis of the manoeuvres and ship dynamics for each exercise. Subsequently, the tool's evaluation pages were saved and flagged by the students to make them accessible to the instructors for assessment and grading. The instructors would revert to the students with feedback on their evaluation pages and written analyses when needed.

Data Collection

At the end of the course, the students were asked to voluntarily evaluate their use experience of the tool and instructed assignments through a short online questionnaire produced and administered through the SurveyMonkey online service. The questionnaire was developed for this context (Fife-Schaw, 1998) by the course coordinator in collaboration with the members of the tool-providing organization (the tool developer and the researcher). The questionnaire consisted of ten questions, closed- and open-ended (combining qualitative and quantitative data (Creswell, 2014; Creswell & Clark, 2011)):

- **Q1** – How difficult was it to use Seaman Online™? (Likert scale from 1 "*Very difficult*" to 5 "*Very easy*") Please give an example of what was difficult.
- **Q2** – How satisfied were you with the stability of Seaman Online™ (e.g., lagging issues, crashes, etc.)? (1 "*Very satisfied*" to 5 "*Very dissatisfied*") Please give an example of any problems encountered.
- **Q3** – How much time did you spend using Seaman Online™? (*1-5 hours; 6-10 hours; 11-15 hours; 16-20 hours; 21-25 hours; more than 26 hours*) Please also comment on how much you used Seaman Online™ to test other manoeuvres not related to the given tasks.
- **Q4** – On which exercise did you spend most time? (*Exercise 1 (IMO turning circle test deep and shallow waters); 2 (interaction and bank effects); 3 (berthing PCTC); 4 (berthing PCTC with tugs)*) Comment.
- **Q5** – Which exercises did you consider as most useful and which ones least? Why?
- **Q6** – How helpful was Seaman Online™ in your learning experience with regard to understanding the effects of shallow water, interaction and bank effects? (1 "*Extremely valuable*" to 5 "*Not at all valuable*") Comment.
- **Q7** – How helpful was Seaman Online™ in your learning experience with regard to manoeuvring ships alongside with and without tugs? (1 "*Extremely helpful*" to 5 "*Not at all helpful*") Comment.
- **Q8** – How useful did you find the data and graphs on the "evaluation page" when analyzing your simulation runs? (1 "*Extremely useful*" to 5 "*Not at all useful*") Please state which information on the evaluation page was most useful and what information you were missing.
- **Q9** – What are the things that you like most about Seaman Online™?
- **Q10** – What are the things that you would most like to improve in Seaman Online™?

Data Analysis

The online questionnaire service used recorded automatically all student responses and provided simple descriptive statistics (frequencies) on the closed-ended questions. These results, along with the responses from the open-ended questions Q5, Q9 and Q10 and the qualitative commentary on all remaining questions, were later discussed during two debriefing sessions: the first with the instructors and the tool developer, focusing on aspects of the design and function of the tool; and the second with the instructors and the researcher from the tool-providing organization, following up on the design of the tool, its usefulness for both students and instructors, and implementation with the students in the context of the university course. Both sessions were audio-recorded and/or documented/annotated. The collected qualitative data from both the questionnaire and the debriefings were then analysed by the researcher in terms of recurring answers/aspects (Creswell & Poth, 2018; Joffe & Yardley, 2004) of interest for aims (a) to (c) of this paper (e.g., the advantages of the tool, such as flexible use; needed design improvements, such as lagging and crashing; more instruction and debriefings needed in implementation).

RESULTS

The questionnaire results show (see Table 2 for descriptive statistics) that 73.91% of the respondents claimed to spend between 1-10 hours using Seaman Online™, whereas the remaining reported to spend 11 hours or more on it. It is also known that 52.17% of the respondents perceived Seaman Online™ as fairly easy to use, whereas 30.43% did not have a specific opinion and 17.39% perceived it as difficult. The reported difficulties ranged from getting familiarized with the layout and the controls of the tool's interface, zooming in on the chart (especially important considering that laptop screens are relatively small, and an additional larger monitor could provide a better experience), or experiencing a delayed response of the system, or even the crashing/freezing of the system. In fact, lagging (particularly when changing speed/thrust using specific internet browsers, or using the 'head-up' chart setting or bow thrusters) and crashing/freezing (especially after pausing and resuming an exercise) were the most commonly reported tool stability issues. This helps to explain the 21.74% dissatisfaction rate with regards to the stability of the tool and may also explain the 34.78% of "neither satisfied nor dissatisfied" responses. Still, 43.48% reported being satisfied with the stability of the tool.

Table 2. Overview of the quantitative questionnaire results.

Closed-ended question	Response frequencies
Q1	0.00% (0/23) "*Very difficult*" 17.39% (4/23) "*Difficult*" 30.43% (7/23) "*Neither difficult nor easy*" 39.13% (9/23) "*Easy*" 13.04% (3/23) "*Very easy*"
Q2	4.35% (1/23) "*Very satisfied*" 39.13% (9/23) "*Satisfied*" 34.78% (8/23) "*Neither satisfied nor dissatisfied*" 13.04% (3/23) "*Dissatisfied*" 8.70% (2/23) "*Very dissatisfied*"
Q3	34.78% (8/23) "*1-5 hours*" 39.13% (9/23) "*6-10 hours*" 17.39% (4/23) "*11-15 hours*" 8.70% (2/23) "*16-20 hours*" 0.00% (0/23) "*21-25 hours*" 0.00% (0/23) "*more than 26 hours*"
Q4	4.35% (1/23) "*Exercise 1 (IMO turning circle test deep and shallow waters)*" 4.35% (1/23) "*Exercise 2 (interaction and bank effects)*" 69.57% (16/23) "*Exercise 3 (berthing PCTC)*" 21.74% (5/23) "*Exercise 4 (berthing PCTC with tugs)*"
Q6	4.35% (1/23) "*Extremely valuable*" 60.87% (14/23) "*Very valuable*" 30.43% (7/23) "*Somewhat valuable*" 4.35% (1/23) "*Not so valuable*" 0.00% (0/23) "*Not at all valuable*"
Q7	13.04% (3/23) "*Extremely helpful*" 65.22% (15/23) "*Very helpful*" 13.04% (3/23) "*Somewhat helpful*" 4.35% (1/23) "*Not so helpful*" 4.35% (1/23) "*Not at all helpful*"
Q8	0.00% (0/23) "*Extremely useful*" 43.48% (10/23) "*Very useful*" 43.48% (10/23) "*No opinion*" 13.04% (3/23) "*Not so useful*" 0.00% (0/23) "*Not at all useful*"

Other important aspects reported referred to perceived flaws in the realistic representation of ship behaviour, namely due to wind, speed or thruster changes. The instructors also detected an unrealistic tugboat model and behaviour when using the "indirect mode". Students reported that there seemed to be a discrepancy in ship behaviour and wind effects between Seaman Online™ (especially when performing exercise 3) and the bridge simulators when performing a very similar exercise. Exercise 3, besides having been considered the most fruitful exercise of all four, was also the one where most respondents (69.57% of them) reported spending the longest time compared to the other exercises. Some considered it to be harder to perform on Seaman Online™ than in the bridge simulators, so much so that a student even suggested this exercise should be performed only in the bridge simulators rather than in Seaman Online™. This discrepancy in ship behaviours and difficulty levels could be later explained by the instructors at a debriefing session by the fact that Seaman Online™ was presenting more realistic wind (i.e., including wind gusts) compared to the exercise run in the bridge simulators where the wind speed was set as constant (in addition, the more realistic feel of the bridge simulators compared to Seaman Online™ could have potentially caused an influence as well). This discrepancy in wind settings had initially not been noticed by the instructors and some of the respondents' comments indicated that it had not been noticed by them either.

The usefulness of the graphs and information presented on the evaluation page after each exercise received mixed reviews (43.48% perceived it as "very useful" and 43.48% had "no opinion"). Negative comments revolved mostly around (a) the difficulty of interpreting some graphs and information provided on the evaluation page (the instructors referred specifically to the terminology and power units being used), and (b) the absence of other information that the respondents suggested would be good to have (e.g., a graph about the ship's squat effects, a circle radius function rather than a simple line to measure distances, and a playback function to be able to rerun an animation of their own exercises once completed). In terms of advantages, the respondents referred to the evaluation page as a good complement to see all hydrodynamic forces and how they affected the ship. The instructors suggested at a debriefing adding an element of evaluation throughout the exercise execution as well, namely live force vectors on the screen, representing bank and interaction forces on the ship.

On a general level, the respondents perceived the online ship manoeuvring training tool as a useful complement to the desktop and bridge simulators, and an opportunity to test manoeuvres and situations that they would otherwise not have the possibility to test in the desktop or bridge simulators or onboard vessels. One of the preferred aspects was that the tool can be used from home, without having to commute to the university or wait for available timeslots to use the simulation rooms for simple manoeuvres or assignments. Overall, 65.22% of the respondents found the tool to be really valuable for learning about shallow water and bank effects and ship interactions, as well as 78,26% found it to be really helpful for manoeuvring with and without tugboats. There were suggestions by the respondents to be able to connect the online tool to the desktop and bridge simulators at the university, and possibly allowing for multi-player scenarios.

The online tool was seen by the instructors as a good replacement of the old software on stationary computers and a complement to the other available resources (the course coordinator even considered it a better tool for training e.g., ship interactions, compared to the desktop or bridge simulators), facilitating that the students do specific course assignments in a more flexible manner to learn about manoeuvring before moving on to the ship handling simulation exercises in the bridge simulators. The tool was also used in class, during a tugboat manoeuvring lecture, as a medium for the instructors to visually demonstrate to the students ship manoeuvres while explaining them verbally.

DISCUSSION

The aim of this study was to obtain (a) feedback about the usefulness of the tool in manoeuvring training; (b) design feedback for its further improvement and usability; and (c) feedback on how to best incorporate it into the programme curriculum in coming academic years for improved user experience.

Study Aim (a). Overall, based on the results of the questionnaire, the majority of the respondents had a positive outlook on the tool for individual technical training of manoeuvring, ship interactions and hydrodynamic effects. It not only provided more flexible individual training for the students but was also perceived by the instructors as a new layer of education, evaluation and feedback within the course curriculum, for stepwise simulation-based training with other available simulation devices/facilities. There is even potential in the tool to be used as a medium for communication and exchange between instructors and students during lectures, as a visualization facilitator.

Study Aim (b). In terms of design improvements, issues such as getting familiarized with the layout and the controls of the tool's interface, zooming in on the chart, using the tool on a laptop's small screen, experiencing tool lags and crashes/freezes or imprecise tugboat model behaviour, interpreting and adding data to the evaluation module, among other issues and suggestions, were pointed out. These are aspects of the usability and maturity of the tool to be refined for further improved use experience. For example, with regards to the controls/keyboard input possibilities, the lagging and crashing/freezing of the system, it was suggested that these should either be technically resolved or clearer user instructions should be provided on the screen on how to use or what to expect from the system (e.g., what system requirements the tool has in order to function properly, or show a count-down clock of how long an exercise can be paused and resumed before it is erased). When properly designed, simpler and more cost-effective simulation devices such as Seaman Online™ can be a successful training alternative and complement to more complex full-mission simulations (Beaubien & Baker, 2004).

Study Aim (c). Results such as (a) the misunderstanding of ship behaviour and the difficulty levels completing exercise 3 with wind effects, (b) the perception of the tool's fidelity level being lower than that of the bridge simulators, or (c) the suggestion to add a multi-player function are all indicative of the need to brief, clarify and debrief the students about the purpose and the boundaries of the simulation device in terms of the course curriculum objectives, in conjunction with the other simulation devices made available in the course, in order to maximize the learning opportunities. This can be re-emphasized when performing debriefings with the students after each exercise. Debriefings (Sellberg, 2017, 2018) can also gauge and ensure that the students do not learn something incorrectly, especially in such circumstances where they are doing simulation exercises outside of instructor supervision. It is also important to understand that a simulated environment may always have inconsistencies and limitations. This study, thus, suggests, that the effectiveness of the simulation technology will not only depend on what it is used for and how it is used (Beaubien & Baker, 2004), but also on how it is introduced to (as well as instructed, guided and debriefed) – and understood by – the trainees in terms of simulation objectives and boundaries, as this had an influence on the students' perceptions and experiences with the tool. Realism becomes then a product of the instructions as well, rather than of the intrinsic technical features of the simulator alone (Sellberg, 2018).

It is unquestionably essential to the training programme that the simulation device can mimic a real-life bridge scenario as realistically as needed for the specific training objectives and competencies it pertains to develop (even though it does not fully replace all onboard training) (IMO, 2017). However, in terms of expectation, experience and assessment, it is also important that the trainee fully understands how the simulation tool is meant to be used and what it is being used for (IMO, 2017), so that they are able to focus on the content of the training and future work practices rather than the form.

Assigning a very similar exercise to the students on two separate simulation devices as was done for exercise 3, for example, may pertain to the development of different skills (in fact, exercise 3 on Seaman Online™ was assigned with the intent of preparing the students for the later similar exercise in the bridge simulators), and this must be understood by the trainees in terms of differences and how they serve as a complement to each other within the course curriculum.

The goal of simulations is practice, reflection and feedback (Maran & Glavin, 2003). The instructors intended that different resources in the course would be used for different purposes and this had not necessarily been fully gathered by the students, which was a lesson learned in that instructions need to be clearer in this sense. The instructors' specific intentions and expectations with Seaman Online™ were that it should help the students to reflect on the behaviour of the ship – to execute a manoeuvre and observe and reflect on what happens in terms of hydrodynamic forces on the ship. This pertains to the individual development of the technical skill that is ship handling. Adding another layer to this tool (as was suggested by a respondent with adding a multi-player function, for example), may have made the scenarios more realistic, but potentially added unnecessary complexity and distraction to the trainee and diminished the control of the instructors over individual student assessment. Different levels of simulation throughout different points of the curriculum are normally required for training (Beaubien & Baker, 2004). At early stages of simulation-based training, one may prefer to simplify a certain task to exclude distractions, to then introduce layers of simulation complexity more gradually as to facilitate the acquisition of competencies and the transference of those competencies between the different levels of simulation and a real-life scenario. Complex simulation techniques have been found to be less suitable in basic skill training, and different types of simulation technologies can be used as a complement to each other to increase fidelity (Maran & Glavin, 2003), as was the intent during this implementation. If the instructors can capture through the tool the skills they want their students to develop, the technical fidelity level of the tool may become less important, especially when in combination with other types of simulation technologies.

CONCLUSIONS

Seaman Online™ is a novel web-based manoeuvring simulation training tool created with the intent of offering both students and professional mariners the possibility to safely practice ship manoeuvres in ports and confined areas from their personal computers. This paper describes the first-time implementation of this simulation tool in the context of a university course in a Master Mariner programme. The aim of this study was to assess proof of concept and use experience of Seaman Online™ as part of the course's resources and obtain (a) feedback about the usefulness of the tool in manoeuvring training; (b) design feedback for its further improvement and usability; and (c) feedback on how to best incorporate it into the programme curriculum in coming academic years for improved user experience. To address these goals, the implementation was followed up by an online questionnaire for the students and the results were then discussed among the course instructors and the tool-providing organization during two debriefings. Feedback pertaining to maturity and usability details and issues in the tool was obtained (e.g., getting familiarized with the layout and the controls of the tool's interface, zooming in on the chart, using the tool on a small laptop screen, experiencing tool lags and crashes/freezes or imprecise tugboat model behaviour, interpreting and adding data to the evaluation module), but most importantly the results revealed that additional attention must be put onto explaining to the students the simulation device in relation to the course curriculum, its objectives in conjunction with the other simulation technologies used, and its limitations. In conclusion, certain aspects of the design and implementation should be refined for the coming academic year, but, even as is, the usefulness and potential of the tool for individual technical training in manoeuvring, ship interactions and hydrodynamic effects were demonstrated.

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REFERENCES

Baldauf, M., & Benedict, K. (2018). Full mission and fast time simulation for shiphandling training. *Seaways*, 6-10.

Baudu, H. (2014). *Ship handling* (1st ed.). Enkhuizen, The Netherlands: Dokmar Maritime Publishers B.V.

Beaubien, J. M., & Baker, D. P. (2004). The use of simulation for training teamwork skills in health care: how low can you go? *Quality & Safety in Health Care*, *13*, i51–i56. doi:10.1136/qshc.2004.009845

Costa, N. A. (2018). *Human-centred design for maritime technology and orgnaizational change.* (Thesis for the Degree of Doctorate of Philosophy), Chalmers University of Technology, Gothenburg, Sweden. (4448)

Costa, N. A., Holder, E., & MacKinnon, S. N. (2017). Implementing human centred design in the context of a graphical user interface redesign for ship manoeuvring. *International Journal of Human-Computer Studies, 100*(2017), 55-65. Retrieved from http://www.sciencedirect.com/science/article/pii/S1071581916301744. doi:10.1016/j.ijhcs.2016.12.006

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). USA: SAGE Publications, Inc.

Creswell, J. W., & Clark, V. L. P. (2011). *Designing and conducting mixed methods research* (2th ed.). USA: SAGE Publications, Inc.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). USA: SAGE Publications, Inc.

da Conceição, V. P., Dahlman, J., & Navarro, A. (2017). What is maritime navigation? Unfolding the complexity of a Sociotechnical System. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 61*(1), 267-271. doi:10.1177/1541931213601549

Dahlström, N., Dekker, S., van Winsen, R., & Nyce, J. (2009). Fidelity and validity of simulator training. *Theoretical Issues in Ergonomics Science, 10*(4), 305–314.

Fife-Schaw, C. (1998). Questionnaire design. In G. M. Breakwell, S. Hammond, & C. Fife-Schaw (Eds.), *Research methods in psychology* (pp. 174-193). UK: SAGE Publications Ltd.

Grech, M. R., Horberry, T. J., & Koester, T. (2008). *Human factors in the maritime domain*. United States of America: CRC Press, Taylor & Francis Group, LLC.

Hamstra, S. J., Brydges, R., Hatala, R., Zendejas, B., & Cook, D. A. (2014). Reconsidering fidelity in simulation-based training. *Academic Medicine, 89*(3), 387-392. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/24448038. doi:10.1097/ACM.0000000000000130

Hornbæk, K. (2006). Current practice in measuring usability: Challenges to usability studies and research. *International Journal of Human-Computer Studies, 64*(2), 79-102. doi:10.1016/j.ijhcs.2005.06.002

IMO. (2017). International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). In I. M. Organization (Ed.), (2017 ed.). London, UK: International Maritime Organization.

ISO. (2002). ISO/TR 16982: Ergonomics of human-system interaction — Usability methods supporting human-centred design. In (1st ed.). https://www.iso.org/standard/31176.html: ISO.

ISO. (2010). ISO 9241-210 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems. In *ISO 9241-210*. Geneva: International Organization for Standardization.

Joffe, H., & Yardley, L. (2004). Content and thematic analysis. In D. F. Marks & L. Yardley (Eds.), *Research methods for clinical and health psychology*. London, UK: SAGE Publications Ltd.

Jordan, P. W. (1998). *An Introduction to Usability*. UK: Taylor & Francis Ltd.

Lewis, J. R. (2014). Usability: Lessons Learned … and Yet to Be Learned. *International Journal of Human-Computer Interaction, 30*(9), 663-684. doi:10.1080/10447318.2014.930311

Lützhöft, M., & Vu, V. D. (2018). Design for safety. In H. A. Oltedal & M. Lützhöft (Eds.), *Managing maritime safety* (pp. 106-140). Milton Park, Abingdon; New York, NY: Routledge.

Maguire, M. (2001). Methods to support human-centred design. *International Journal of Human-Computer Studies, 55*(4), 587-634. doi:10.1006/ijhc.2001.0503

Manuel, M. E. (2011). *Maritime risk and organizational learning*. UK: Ashgate.

Maran, N. J., & Glavin, R. J. (2003). Low- to high-fidelity simulation – a continuum of medical education? *Medical Education, 37*, 22–28.

Nielsen, J., & Mack, R. L. (1994). *Usability inspection methods*. USA: John Wiley & Sons, Inc.

Norman, D. A. (2013). *The design of everyday things* (Revised and Expanded Edition ed.). United States of America: Basic Books.

Sellberg, C. (2017). From briefing, through scenario, to debriefing: the maritime instructor's work during simulator-based training. *Cognition, Technology & Work, 20*(1), 49-62. doi:10.1007/s10111-017-0446-y

Sellberg, C. (2018). *Training to become a master mariner in a simulator-based environment.* (Thesis for the Degree of Doctorate of Education), University of Gothenburg, Gothenburg, Sweden.

Chasing the end-user perspective in bridge design

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Abstract - **Navigators onboard maritime vessels often interact with several different electronic navigation systems from different equipment manufacturers, leading to a variety of user interfaces, panels and operating philosophies on the bridge. This may influence safety as it may lead to sub-optimal workflow and increased cognitive load. Rolls-Royce Marine (now Kongsberg Maritime CM) have developed a bridge environment aiming to unify the user experience by simplifying and standardising the different workstations on the bridge. The end-users were involved at several stages during the design process. This paper reports the findings from two field studies performed on two platform supply vessels with the Rolls-Royce Unified Bridge installed. Ethnographic inspired data collection was performed to reveal the navigator's opinions of this bridge environment. The main finding is that the they found this bridge to be overall user-friendly and well arranged. They also pointed at a few solutions that can be improved.**

Keywords
Bridge design, human-centred design, ethnography, evaluation.

INTRODUCTION

On June 8, 2009 the vessel *Big Orange XVIII* was en route to the 2/4-X-platform on the Ekofisk field to perform well stimulation (Kvitrud, 2011; Leonardsen, Jacobsen, & Hamre, 2009). At 04:00 the captain took over command on the bridge, the Ekofisk radar was contacted for permission to enter the 500-meter zone and the captain changed from autopilot to manual steering. After a couple of minutes, there was an incoming phone call to the bridge. The captain switched the steering back to autopilot and left the steering position to take the phone call in the radio room adjacent to the bridge. The conversation lasted for about 30 seconds. When he returned to the steering position he did not deactivate the autopilot again. At 04:11 *Big Orange XVIII* received permission to enter the 500-meter zone. The captain reduced the speed to make a turn and position the vessel alongside the installation. He then became aware that the vessel did not respond to manoeuvring attempts. The vessel managed to avoid collision with platforms 2/4-X and 2/4-C by passing under the bridge between them. Thinking there was a technical problem with the steering the captain did several attempts to manually manoeuvre the vessel to stay clear of the installations. The vessel passed very close to the jack-up flotel COSL Rigmar before it finally collided with the unmanned water injection platform Ekofisk 2/4-W at 04:17. There was no physical injury to personnel, but significant material damage to both the platform and the vessel. For one thing the production from Ekofisk 2/4-A had to be shut down. The investigation reports pointed at several underlying causes for the accident (Kvitrud, 2011), however the main direct cause being the captain did not realize that the autopilot was switched on during the entire approach.

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Collisions between attendant vessels and offshore facilities are example of marine accidents that have a very high hazard potential. In addition to the risk for the personnel involved, damage to hydrocarbon pipes may cause severe oil spills and thus represents a threat to the environment. During the period 2001–2011, a total of 27 collisions were reported between attendant vessels and offshore facilities on the Norwegian continental shelf (Sandhåland, Oltedal, & Eid, 2015). Ibid found that "errors due to reduced vigilance and misconceptions of the technical automation systems emerged as the primary antecedents of collisions".

There are many factors that influence how a seafarer make sense of his/her environment, ranging from individual factors (human senses, perception, fatigue, workload and stress), communication and team work (roles, leadership), work environment (light, noise), to cultural aspects (safety culture, national culture) (Grech, Horberry, & Koester, 2008). Seafarers today are working in a technology dense environment on the bridge, interacting with highly advanced automated systems. The design of technology influences the way people work and how they perform. The *Big Orange XVIII* accident is for one thing an example of how fragile the human short-term memory is. But well-designed technology should support humans including human shortcomings like these. It seems that the Human-Machine Interface (HMI) on *Big Orange XVIII* did not convey a clear message to the captain regarding who was in control of the steering.

In addition to individual equipment not always having good interface design, many ship bridges consist of equipment delivered by multiple vendors. Nordby, Frydenberg & Fauske (2018) found that multivendor ship bridges may consist of up to 35 different types of equipment. The separate equipment units are usually installed in large work consoles leading to cluttered workplaces and suboptimal workflow for the navigators. Due to lack of standardization in the maritime industry, different companies have different user interface design. It requires cognitive workload to switch between different user interfaces, it also increases the need for familiarization and training.

Rolls-Royce Marine (now Kongsberg Maritime CM) is a commercial actor that have incorporated Human-centred design (HCD) in the development of maritime equipment. They set out to develop an integrated bridge based on research and knowledge about the actual work context and performed a complete redesign of the ship bridge environment, including consoles, levers and software interfaces (Bjørneseth, 2014). One of the objectives was to achieve consistency across applications concerning the graphical user interface (Bjørneseth, Dunlop, & Hornecker, 2012). The end-users were involved at several stages throughout the design process.

This paper reports the findings from two field studies performed on two platform supply vessels (PSV) with the Rolls Royce Unified Bridge installed. Ethnographic inspired data collection was performed to reveal the navigator's opinions of this particular bridge environment. The work aimed at performing a user-centred evaluation after long-term use which can provide input for improvements for future versions of the product.

BACKGROUND

Safety through design

The maritime industry is a high-risk industry as accidents may have severe consequences for human lives, the environment or the economy. The cause of accidents in this sector are often attributed to "human error", e.g. Dhillon (2007) reported that over 80 percent of marine accidents are caused of influenced by human and organizational factors. According to AGCS (2017), 75-96% of marine accidents can be attributed to "human error" as "a number of incidents have occurred where crews have relied too much on technology, particularly involving electronic navigation tools." (AGCS, 2017). As pointed out in the AGCS report, it is often problematic for humans to interact with technology. A maritime system, like the bridge on a vessel, is a system where human, technological and organizational factors influence each other. How humans interact with other system components are predetermined in design (Lützhöft and Vu, 2018). Faulty design may make the interaction between humans and the other system components difficult which may lead "human error". Lützhöft and Vu (2018) states that "it is faulty design, not 'human error', that is the primary, or latent, reason behind accidents in the maritime industry". Design has also been reported as a significant contributor to accidents in other domains, like aviation, railway and nuclear (Kinnersley & Roelen, 2007). Hence, it is a safety issue that design can accommodate the needs, capabilities and limitations of the humans.

Human factors can be defined as "the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance" (Salvendy, 2012). It has been suggested that within the human factors discipline the sensemaking perspective (Weick, 1995) may be a useful concept for understanding human behaviour on the bridge (Danielsen, 2018). Sensemaking concerns the cognitive processes through which people work to understand issues or events, by extracting cues from the environment and through cycles of interpretation and action create meaning to these events (Maitlis & Christianson, 2014). Scholars have described sensemaking as a factor influencing resilience (Takeda et al., 2017, Grøtan and van der Vorm, 2015).

Considering human factors knowledge in design has been implemented in maritime regulations, as seen in SOLAS (Safety of Life at Sea) regulation V/15 regarding the design of ship bridges, bridge equipment and procedures. SOLAS V/15 has formulations like "allowing for expeditious, continuous and effective information processing and decision-making by the bridge team and the pilot" which promotes human-centred design that accommodates sensemaking. The International Organisation for Standardisation defines human-centred design as "an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques." (International Organisation for Standardisation, 2010). Human-centred design implies a throrough understanding of the user and the work context and involves iterative activities like data collection, analysis and producing design solutions. To develop a proper understanding of the work context in the maritime sector Lurås & Nordby (2015) stress the importance of field work to develop a "designers sea sense".

Human-centred design has been reported to have an added-value in the maritime sector, benefitting the seafarers in terms of physical cognitive, psychosocial and organizational improvements as well as having certain benefits for the ship-owners, such as reduction of costs (Costa & Lützhöft, 2014).

A human centred design process should also include evaluation at several stages during project development. According to the standard ISO 9241:210 user centred evaluation (evaluation based on users' perspective) is a required activity in human-centred design (International Organisation for Standardisation, 2010). User-centred evaluation is considered useful in all stages of in the project from the early concept of the design to its long-term use. Within research it has also been suggested that in order to "observe change due to the introduction of technology, we should be there a) immediately when it is introduced, b) when it is in use, and c) when users have adapted to it." (Lützhöft, 2004 p20). It is argued that certain types of problems or tailoring will be visible at certain time periods after introduction of technology.

The Rolls-Royce Unified Bridge

Rolls-Royce Unified Bridge started as a conceptual innovation project to define the next generation ship bridge. The goal of the project was to increase operational safety in demanding maritime operations through redesigning the ship bridge environment, including consoles, levers and software user interfaces utilizing a human-centred design process. The human factor and physical ergonomics were the basis of development in order to introduce a more comfortable and safe working environment for the operators on-board, making it user centric and flexible. Above all, it should unify the user experience in one single concept – the Unified Bridge.

To think holistically on the complete operation, from the human perspective, the involved functions, systems and equipment, the complete interactions on the ship bridge (the control centre) was important to gain enough insight to coordinate the different initiatives and produce a physical design on consoles, levers and graphical user interfaces for software applications. The Unified Bridge philosophies including unified alert handling (silencing alerts from one location), unified look and feel on all software applications (including symbols, navigation patterns etc.) and unified dimming of lights on the bridge from a remote-control application (described below), are vital parts of the innovation concept. Following the unveiling of an initial design concept at a leading maritime exhibition, development work began based on the four design principles:

- Safety
- Performance
- Proximity
- Simplicity

The development process included collection of qualitative data through interviewing ship operators; carry out studies in the field to view functional designs and doing observation and usability studies, including a thorough mapping of any relevant rules and regulations. On a detailed level, prototypes (lo and hi – fidelity) of all physical devices (consoles, levers and chairs) were developed and thoroughly tested involving users throughout the process from drawing to final concept. Verification methods such as hierarchical task analysis, functional task analysis and eye-tracking equipment were also used to assess frequency of equipment usage, important tasks/functions and optimize placement of monitors, levers and operational equipment.

The project proceeded in close co-operation with industrial designers. The Rolls-Royce Unified Bridge project proceeded in two parallel runs where one part of the project was the development project, developing new technical solutions, graphical user interfaces, consoles, operator chairs, levers etc. The other part of the project was a research project supported by the Norwegian Research council, doing testing and evaluations of the concept. With this project composition, it was possible to feed the research results directly into the development project for instant implementation.

To optimize the traditional over-equipped work surfaces to set focus on the operation-critical equipment, a number of individual sets of equipment from third party suppliers were replaced with a new integrated product that could remote control equipment that was important for the vessels operation, however not vital for the actual operation that was carried out. Lantern, searchlight, bridge light and window viper control are a small collection of the equipment remote controlled from the bridge station through a touch-screen computer solution. In traditional ship bridges, the above-mentioned equipment are independent systems, that on their own has large single panels that occupy important space close to the operator. By moving such equipment to a bridge equipment station further away from the operational zones, the original panels are still available to the operators, but with the possibility of remote control. This leaves the operation-critical equipment in closer proximity to the operator.

Initially the concept was developed for platform supply vessels but has been extended to a range of different vessel types, such as cruise, tug, ro-pax, construction, double-ended ferries, mega yachts, service- and fishing vessels. The expansion of the Unified Bridge concept to other vessel types has shown that the philosophy behind the concept with focus on the holistic operational environment and user experience is generalizable to most vessel types. As an example, the Unified Bridge cruise concept, installed on the new *MS Roald Amundsen* owned by Hurtigruten, has the same holistic philosophy as the specialized supply vessels, but the consoles have been adapted to suit the operational pattern for exploration cruise vessels. The bridge wing on these vessels are of more importance than the bridge wing on supply vessels. Mainly because the vessels arrive at many different ports during their journey and the bridge crew needs full overview of the ship side when porting. Also, tender operations when tourists go exploring in smaller RIB boats that are boarded at sea requires good overview of the ship side. Another example is fishing vessels where the Unified Bridge concept has been adapted to suit the typical operational patterns when fishing. Fish searching equipment and a videowall is vital when looking for suitable locations for fishing. Depending on the type of fishing vessel, the aft bridge or the bridge wing has important functions that much be taken into consideration.

In general, field studies, interviews and gathering insight within the field of interest, has been an important step for Rolls-Royce Marine (now Kongsberg Maritime CM) when new products are to be developed, or when revitalizing already established products. The insight gathered from the investigations has been used as the foundation for development. The user has been involved throughout the development process from idea to finished product being released into the market. Throughout the products' lifecycle, the users are still involved by returning insight of product utilisation to the product owner for them to include in new improved versions of the products.

METHOD

Sample

Fieldwork was conducted on board two offshore supply vessel owned by a Norwegian shipping company. The vessels, built in 2014 and 2016, were equipped with the Rolls Royce Unified Bridge. Figure 1 illustrate the overall layout of the bridges.

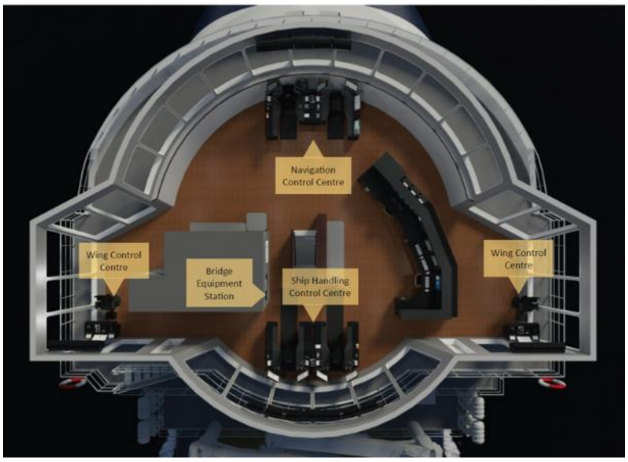

Figure 1. Illustration of the Unified Bridge arrangement on the PSV bridges.

Both vessels had four Norwegian officers on-board that participated in the study. They had all trained at Norwegian maritime educational institutions and had worked on these particular vessels from 1-4 years. Their shift rotation was 4 weeks on board and 4 weeks off. On board each ship the four officers were divided in two shifts that for 24 hours had 7 hours work, 5 hours rest, 5 hours work and 7 hours rest. The current study is part of a research project that has been notified with NSD – Norwegian Centre for Research Data, to make sure any personal data collected is managed in compliance with Norwegian legislation. The study was approved by the shipping company and all officers signed participant consent forms.

Data Collection

The fieldwork was performed by the first author and lasted for a three and a four-day period while each vessel was operating on the Norwegian continental shelf. As the time spent in the field was relatively short, it was not possible to perform ethnography in the traditional sense. Hence, selected aspects in this context were studied, also known as Micro-Ethnography (Bryman, 2016) focusing on the officer's work processes and interaction with the equipment on the bridge. Observation on the bridge was performed around 12 hours a day (with short breaks) and included semi-structured interviews while the officers were working, taking care not to disturb operations. The questions asked were general, open questions regarding the officer's thoughts about the Unified Bridge in general, positive and negative aspects of integrating bridge equipment and how this bridge environment was perceived compared to other bridge environments they had worked with. In addition, more specific questions about the available equipment were asked, e.g. what they thought about the thruster levers, the chair, placement of screens, alarm management and so on. The field notes were written in between the observation periods when the observer withdrew to the cabin, as the conversations with the officers was experienced to flow more naturally when the notebook was not visible. Hence, the quotations in this paper are translated from Norwegian to English and as remembered by the observer. Pictures that were taken during observations and conversations with crew turned out to be a good aid for remembering what had been discussed when writing field notes.

Methodological challenges

The observer in this study was inexperienced both in the maritime sector and as an observer. The observer initially set out to collect data on how seafarers make sense of their environment, particularly how the electronic navigation equipment could support their sensemaking. By being inexperienced in the field the observer may have misunderstood what the information or data meant to the informants or may have missed or misunderstood situations that occurred or the content when the officers discussed with each other. However, the advantage of being an "outsider," is asking what may possibly be perceived as naïve or simple questions, making the informants thoroughly explain equipment functions and work processes, that insiders might take for granted.

In addition to the main focus which was the officer's interaction with the equipment on the bridge, the observer also initiated discussion on topics like professional culture or how the informants experienced being away from their family for long periods of time. As qualitative research is about understanding and interpreting the meaning of informants, discussing additional topics may have been beneficial for the analysis. Still, the findings in this paper is mainly based on what the officers explicitly expressed regarding the bridge equipment.

Although ethnography is context specific, the findings may be transferable and of interest for designers and engineers involved in development of integrated ship bridges or HMI in general for use in the maritime sector.

As described in the findings section, the officers often used the term "getting used to" when they described interaction with equipment. An effect of evaluation at this stage, after the bridge system has been in use for several years, is that it may not reveal problematic issues as the humans have adapted to their work environment. The findings could be strengthened by further work where including a combination of methods, like quantitative measurements or the use of a domain expert or a human factors expert.

FINDINGS AND DISCUSSION

In this section the findings from the field studies are presented and discussed. First the findings from the bridge environment in general is discussed, followed by the findings from the main pieces of equipment that were redesigned as part of the Unified Bridge concept; the consoles, Graphical User Interfaces, levers, chairs and alarm philosophy. The last section describes crew concerns regarding integrated bridge systems. For overview a summary of the main findings is presented in Table 1.

Table 1. A summary of the main findings from this study, presented as design success or design issue.

Item	Design success	Design issues
The overall bridge design	Users found it "user-friendly" and "well arranged".	None
Consoles	Equipment needed for navigation and DP-operations readily available from main working position. Touchscreen with integrated functions found "practical" and "time-saving". Open front of console accommodate view outside.	Small windows obstruct view in fore steering position. Extra laptop needed on aft console during cargo operations. Blue light by lever base obstruct night vision.
Graphical User Interface	Well-functioning.	An overview display of tanks required 180-degree mental rotation. Colour contrast issue, users found black text on a grey background hard to read.
Levers	Satisfied with size, feedback and scale on thruster levers. Satisfied with three-in-one function of DP joystick, as well as placement of buttons on top and at base.	One lever obstructed view to part of radar-screen. Rudder lever has opposite function to thruster-levers, not used due to fear of confusion.
Chair	Easy to get in/out of. Positive that can be moved back/forward.	Did not accommodate comfortable seating for a seven-hour shift. Backrest broke in high sea-sate and had to be fortified.
Alarm philosophy	Satisfied with unified alarm handling for most alarms on one screen.	Not all alarms were integrated and had to be managed from mid console.

The Bridge Environment

The overall impression of the bridge environment in both vessels was tidy, clutter-free and with very few local adaptations. Local adaptations like marking levers or buttons, adding extra computer mice or cover screens with fabric to dim them can often be found on ship bridges. When the HMI is sub-optimally designed, crew often find workarounds and tailor the HMI to be able to get their job done. In this respect the absence of tailoring and adaptations may in itself indicate that the bridge equipment supports the officers work task in an adequate manner.

When discussing the bridge environment in general, the officers described it as being "very well arranged" and "a very user-friendly system". The underlying reasoning for this opinion was mainly that the equipment was well adapted to their needs. Most of the officers had experience from working with other more conventional bridges and compared the Unified Bridge concept to their previous experience. One of them claimed that "none of us would like to go back to working with a conventional bridge with all the buttons on the consoles". The same officer continued with reflecting on that what he preferred to work with also had do with what he "was used to". When he started working with this bridge he found it a bit cumbersome because he was used to finding things elsewhere. Still he claimed when looking back and comparing the different bridges he had worked with, he preferred the Unified Bridge. Another officer also explained that it took some time for him to get used to this bridge system, especially the touch screen. He came from an old boat with more analogue systems and although "some of the buttons there were very small and hard to find in the dark", he "was used to it". However, after getting used to the touch screens he now preferred this system because "you have everything you need easily available". This passage illustrate not only that they appreciate that equipment has been arranged in a manner that accommodate their work, there is also an element of the officers adapting to the work environment. When looking back on working with ship bridges with poor design, it didn't seem to bother them at the time as they "were used to it". It has been described as part of the seafarer culture to be able to 'handle anything' and adapt to the circumstances at hand (Lützhöft and Nyce 2008). This brought some uncertainty as to whether the expressed positive opinion could be somehow biased due to adaptation. Hence it would strengthen an evaluation to both observe the users immediately when the new technology was introduced in addition to when users have adapted to it. Still, the main finding regarding the overall bridge environment was that the users were positive and content with how their working environment was designed.

The data collection did not reveal any differences between officers due to their experience with this system (whether they had one- vs four-year experience). However, one of the officers had participated in the final stages of the design process where he amongst other things influenced placement of equipment in the consoles. Other officers had also had close contact with engineers from the manufacturer in the first period after the ship was launched where some start-up problems had to be solved. These officers were particularly positive to the bridge system. They had thorough knowledge about the different parts of the technical system and the reasoning behind placement of equipment. Employee participation was also one of the factors identified by Österman, Rose, & Osvalder (2010) as influencing achievement of a good working environment and safety onboard. They found that employee participation could make the crew feel appreciated and heard and positively influence business operations.

Console design

The forward steering position was used when sailing to and from port and offshore facilities as well as between offshore facilities (Figure 2). According to the officers the main task when sailing to/from port with autopilot engaged was looking out of the window to monitor weather and traffic, as well as looking at screens inside to monitor vessel status, the ECDIS- and radar-screens where most frequently used.

Both the fore and aft workstations were open in front and as such not obstructing the view ahead of working position. This solution gave a good view of the deck from the aft steering position where the windows almost covered the entire bulkhead surface. However, in front of the fore bridge the windows were positioned only on upper half of the bulkhead and the officers mentioned that larger windows would have given a better view outside also on the fore bridge. Hence, it is important to include end-user preferences not only in bridge equipment design, but also when designing the vessel itself.

Figure 2. Officer in forward steering position.

As seen in figure 2 the main screens displaying ECDIS and radar were placed in front of the main working position, accommodating the frequent use of these. Other displays e.g. conning display were placed in the overhead and the officers did not express any strong opinion of the positioning of these.

The touch screen placed in the mid console was especially appreciated by the informants (Figure 3). This screen was an integrated product where the navigator could choose what information to go on which screen, they could remotely control equipment like lantern, searchlight, window vipers and dimming of all screens. This screen was described as «very practical» and «timesaving» as they didn't have to spend time «to run around looking for switches». This solution seemed to accommodate what the officers found practical and necessary for performing their main tasks. Activities like "running around looking for switches" were perceived unnecessary and taking up attention from more important tasks.

Being able to dim computer screens are important for the seafarer's night vision. The authors have experienced bridges where all screens had to be dimmed individually or screens not having dimming functions at all where the crew covered them with fabric not to obstruct night vision. In both PSVs the only home-made dimming functions that were observed were on the phone display as well as the blue light by some of the lever bases. The red light by the lever bases was not covered, indicating that choice of colour is important for how much it affects night vision.

The stern steering position was used for Dynamic Positioning (DP) operations when the vessel was positioned alongside the offshore facilities (Figure 3). During DP operations one of the officers was responsible for monitoring the DP system while the other oversaw loading and offloading operations, including communication with people on deck and on the offshore installation. Both officers followed the activity on deck, the loading and offloading of cargo as well as communication with the different stakeholders. The DP system control could be switched between the two positions, a function they at times used when one of the officers had to leave his chair.

Figure 3. Officer in stern steering position. A thruster-lever and the DP joystick can be seen in front of the screen ahead. The touch-panel with integrated functions is facing toward the officer on his right-hand side.

The officers described the DP system in these vessels "the DP system is very good in this vessel" or "this DP system is a lot better than other DP systems I have used". The statements were substantiated by that the displays had shortcuts and there was no need for searching for what they needed in lengthy menus. Another feature that was emphasized was that all information going into the DP checklist could be found on one page, there was no need for looking up information in different locations. This was another example of a very concrete accommodation of user needs that they found very practical. The DP checklist must be completed before entering the 500-meter zone around the installations and are often performed several times a day.

One adaptation was observed on the aft console. The officers in charge of cargo operations added a laptop on the console to use an internet software solution for cargo logistics. The console did not accommodate equipment like this, hence the laptop interfered with the touch screen and the power line was obstructing free passage from the console. There is a continuous development in technology and applications used on the bridge, although challenging, the bridge should be designed in a way to accommodate future changes.

In general, the officers expressed they had everything they needed within reach both in fore and stern steering positions. They very rarely had to move from their working position to perform tasks related to navigation. Some of them even mentioned they felt they were sitting too much during their work hours, especially during DP operations that can last for several hours. Still, the observer's impression was that although sitting their arousal was not so low that it weakened performance according to the Yerkes-Dodson law (1908). During DP operations the officers was continuously engaged in monitoring and coordinating and communicating with the different stakeholders involved in cargo operations.

Graphical user interfaces

The graphical user interfaces (GUI) were not discussed in detail with the officers. They found the GUI in general to be working well. However, they pointed at a couple of points that could be improved in future versions. One was a display that gave an overview of pumps and tanks and their placement in the boat. The overview was displayed in a manner that required 180-degree mental rotation to comprehend the placement in the vessel. As this information was important for proper ballasting of the vessel, one officer expressed concern that errors could be made due to the mismatch between display and vessel directions. One other concern regarding displays came up, and it had to do with colour contrast, where they found black text on a grey background hard to read.

Levers

The officers were positive regarding the thruster levers (Figure 4), they especially emphasized that they were big enough to give good grip and that they gave clear feedback concerning position. The scale on the levers was also well received however, one of the officers explained that he never looked at the scale as «you get a feeling for how much to give when you get to know the boat». Human-centred designed equipment should be generally usable to all types of seafarers. A less experienced navigator may appreciate the possibility of having a scale, although with experience a ship-sense (Prison, 2013) is developed resulting in a more intuitive feeling of how to operate the equipment.

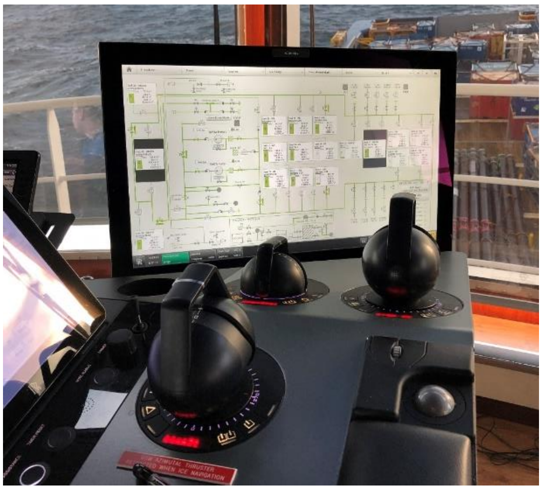

Figure 4. The thruster levers position in the console.

One officer mentioned that the lever placed on the angled front end of the consoles could obstruct the view of information on the lower part of the screens in front of the consoles.

The rudder lever had a different shape than the thruster levers and was also readily available from the steering position. The rudder lever was not used. As opposed to the thruster levers, when turning the rudder lever to starboard the vessel moves to starboard. One of the officers pointed out that he did not want to use it since the function was opposite of the thruster levers and he was afraid that it might lead to making a mistake.

The DP joystick was also described as "very good" and "user-friendly". One officers even described it as "genius" that the joystick had a three-in-one function as opposed to other DP systems he had previous experience from. Other features of the PD joystick they appreciated were the buttons both on top of the joystick and at the base, they functioned very well. They also emphasized the possibility of resting the hand at the base without accidentally pushing the buttons there, as some of them had previous experience on unwanted incidents due to resting the hand on base buttons.

Chair

The operators chair (seen in Figure 2) was the single piece of equipment the officers were most critical towards. It was easy to get in and out of the chair and the possibility to move the chair forward and backwards were often used. However, they basically found it uncomfortable to sit in. Some of the officers described it as too hard while others as too soft, especially the support under the knees. Some found the seat being too short to support the knee. One officer described the chair as being ok in the beginning of the shift but impossible to sit in for seven hours. Another officer mentioned he did not like the headrest as it didn't support the head properly. There were deviating opinions regarding having the armrests attached to the consoles and not the chair. Some thought that these armrests did not give good enough grip in high sea states when you need something to hold on to. Others thought the armrests were functioning well. On both vessels the backrest had to be fortified as they broke during high sea state, an event that influenced how the officers perceived the overall quality of the chair.

Alarm philosophy

The unified alert handling, meaning that alarms could be silenced from one location was another system feature the officers described in positive terms. The alarms were presented on one screen that gave «good overview», "it is easy to detect where the alarms are coming from». As one of the officers explained: "on other vessels you might have to go to the console, read a code and then look up in a manual to figure out what the code means». Handling and prioritizing alarms may in a direct way impact safety. There are examples where crew has disabled audible alarms that could have alerted the crew and maybe prevented an accident (MAIB, 2017). However, not all equipment was possible to integrate in the Unified Bridge system, e.g. the Inmarsat alarm had to be silenced on the console placed in the centre of the bridge.

Integrated Bridge systems and vessel autonomy

Although the integrated bridge system was mainly described in positive terms by the crew, supporting their work tasks in appropriately, integration may affect their job in other ways. The crew were concerned about a development towards vendors controlling more from shore. E.g. troubleshooting or maintenance that previously was done on board now have to be performed remotely by experts on shore. One example was if they saw the need for an additional bridge light, a simple piece of equipment, the onboard electrician could not install it (and immediately solve a problem). It would need reprogramming into the integrated system, this takes time and money, often resulting in that it is not done. Seafarers have previously been found to be sceptical towards organizations on shore (with staff without sailing experience) making decisions concerning the vessels (Antonsen, 2009). The digitalisation of maritime sector will possibly lead to more tasks and responsibilities being performed by the onshore organizations. It might be wise to make an assessment in collaboration with seafarers of how future tasks and responsibilities should be shared between onshore organization and the crew onboard in order to find an arrangement that can work for both parties.

CONCLUSION AND FUTURE WORK

This paper reported the findings from two field trips on board platform supply vessels with the Rolls-Royce Unified Bridge installed. Ethnographic inspired fieldwork was conducted to find the opinions regarding this bridge system from the seafarer's perspective. Overall the officers were very positive, describing the bridge system as being "very well arranged" and "a very user-friendly system". The human-centred design process behind the development of this bridge system seem to have been able to accommodate many of the end-user needs. The design makes sense to the seafarers when it is in line with their work practices. The officers pointed at some points for improvement that is valuable input for future development of the system. They also expressed some concerns regarding the crew's autonomy as integrated bridges may increase supervision and control from shore.

The Unified Bridge has now been in the market for five years and has continuously been improved based on the feedback from the two vessels visited in this study. The results from this particular study is important to the product organisation for two reasons. First, to provide insight to further improve the concept and address the flaws pointed out. Second, to underline the importance of continuing to invest in science-based product development and product improvement, and to confirm that the concept development process incorporating human factors and a user centric process has been a success.

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REFERENCES

AGCS, Safety and Shipping Review 2017. An annual review of trends and developments in shipping losses and safety. 2017: http://www.agcs.allianz.com/.

Antonsen, S. (2009). The relationship between culture and safety on offshore supply vessels. Safety Science 47, 1118-1128.

Bjørneseth, F. (2014). Improving safety on board ships through better bridge design. The Ergonomist (532).

Bjørneseth, F. B., Dunlop, M. D., & Hornecker, E. (2012). Assessing the effectiveness of direct gesture interaction for a safety critical maritime application. International Journal of Human Computer Studies, 70(10), 729-745. doi:10.1016/j.ijhcs.2012.06.001

Bryman, A. (2016). Social Research Methods (5 ed.). UK: Oxford University Press.

Costa, N.A and Lützhöft, M. (2014). The values of ergonomics in ship design and operation. Human factors in Ship Design and Operation, February 2014, London, UK.

Danielsen, B.-E. (2018). "Sensemaking on the bridge: a theoretical approach to maritime information design," Advances in Intelligent Systems and Computing, 876, pp. 76-81. DOI: 10.1007/978-3-030-02053-8_12

Dhillon, B. S. (2007). Human reliability and error in transportation systems: Springer Science & Business Media.

Grech, M., Horberry, T., & Koester, T. (2008). Human factors in the maritime domain: CRC press.

Grøtan, T. O., and van der Vorm, J. (2015). Training for Operational Resilience Capabilities. 6th Symposium on Resilience Engineering, Lisbon, Portugal, June 22-25, 2015

International_Organization_for_Standardization. (2010). Ergonomics of human-system interaction - Part 210 Human-centred design for interactive systems (ISO 9241-210). Retrieved from https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=419711

Kinnersley, S., & Roelen, A. (2007). The contribution of design to accidents. Safety Science 45(1-2), 31-60.

Kvitrud, A. (2011). Collisions between platforms and ships in Norway in the period 2001-2010. Paper presented at the International Conference on Ocean, Offshore and Arctic Engineering, Rotterdam, The Netherlands.

Leonardsen, R. L., Jacobsen, S. R., & Hamre, R. (2009). Granskning av Big Orange XVIIIs kollisjon med Ekofisk 2/4-W 8.6.2009. www.ptil.no

Lurås, S., & Nordby, K. (2015). Shaping designers' sea sense: A guide for design-driven field research at sea. Paper presented at the International Conference on Marine Design 2015.

Lützhöft, M. (2004). “The technology is great when it works”: Maritime Technology and Human Integration on the Ship’s Bridge. Linköping University Electronic Press.

Lützhöft, M., and Nyce, J. M. (2008). Integration work on the ship's bridge. Journal of Maritime Research, 2, 59-74.

Lützhöft, M., and Vu, V. D. (2018). Design for Safety. In H. A. Oltedal and M. Lützhöft (Eds.), Managing Maritime Safety. New York: Routledge.

MAIB. (2017). Report on the investigation of the grounding of Muros, Haisborough Sand North Sea 3 December 2016. (22/2017). Marine Accident Investigation Branch UK

Maitlis, S., and Christianson, M. (2014). Sensemaking in Organizations: Taking Stock and Moving Forward. The Academy of Management Annals, 8(1), pp. 57-125.

Nordby, K., Frydenberg, S., & Fauske, J. (2018). Demonstrating a maritime design system for realising consistent design of multi-vendor ship's bridges. Paper presented at the RINA - International Conference on Human Factors, London, UK.

Prison, J., Dahlman, J. and Lundh, M. (2013). Ship sense-striving for harmony in ship manoeuvring. WMU Journal of Maritime Affairs 12(1): p. 115-127

Salvendy, G. (2012). Handbook of Human Factors and Ergonomics (G. Salvendy Ed. 4th ed.). New Jersey: John Wiley & Sons Inc.

Sandhåland, H., Oltedal, H., & Eid, J. (2015). Situation awareness in bridge operations–A study of collisions between attendant vessels and offshore facilities in the North Sea. Safety science, 79, 277-285.

Takeda, M., Jones, R., and Helms, M. M., 2017, "Promoting sense-making in volatile environments: Developing resilience in disaster management," Journal of Human Behavior in the Social Environment, 27(8), pp. 791-805.

Weick, K. E. (1995). Sensemaking in organizations. Thousand Oaks, Calif: Sage.

Yerkes, R. M. & Dodson, J. D. (1908). The relationship of strength of stimulus to rapidity of habit formation. Journal of Comparative Neurology and Psychology, 18, 459–482.

Österman, C., Rose, L., & Osvalder, A.-L. (2010). Exploring maritime ergonomics from a bottom line perspective. WMU Journal of Maritime Affairs.9(2), 153-168. doi:10.1007/bf03195172

Safety Challenges for Maritime Autonomous Surface Ships: A Systematic Review

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Abstract - **Background: While numerous studies have been carried out regarding the safety of merchant maritime autonomous surface ships, no prior systematic review synthesising their results exists.**
Objective: Systematic review of peer-reviewed journal articles to collect all safety challenges for merchant maritime autonomous surface ships identified therein.
Data Sources: Four databases –SCOPUS, Academic Search Elite, ScienceDirect and Web of Science – were utilised to search for relevant studies.
Results: The review has identified three main groups of challenges, namely technological, human factors and procedural challenges.
Conclusion: Further research is necessary in order to overcome the identified challenges. The qualitative nature of the collision regulations requires further research in order to ensure autonomous ships comply with legal requirements that are worded in a way that makes them open to interpretation.

Keywords
Autonomous; Challenges; MASS; Ship; Systematic Review; Unmanned; Vessel.

INTRODUCTION

Maritime Autonomous Surface Ships (MASS) – provisionally defined as ships "which, to a varying degree, can operate independent of human interaction" (Maritime Safety Committee, 2019) – have received a lot of attention in recent years. However, most of the research carried out on the topic has been focused on overcoming the technological (Banda, Ahola, Gelder, & Sonninen, 2018) and legal challenges involved (International Maritime Organization, 2018), leaving a research gap in how these vessels can safely be operated.

This review aims to summarise the safety challenges for MASS identified in previous research. The summary can be utilised by researchers to get an overview of the research gaps existing in the field, thereby facilitating the process of finding suitable measures to ensure safe operations of MASS.

METHODS

This paper is a systematic review of journal articles discussing safety challenges for MASS.

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Study Design

This review was designed using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (Moher, Liberati, Tetzlaff, Altman, & PRISMA Group, 2009) as a guideline. A copy of the review protocol can be found in (Dreyer, 2018).

Search Strategy

The literature search was conducted using the databases SCOPUS, Academic Search Elite via EBSCOhost, ScienceDirect, and Web of Science. The search strings defined in Table 2 were run on 19 September 2018 in as many fields as the different databases allowed. Literature found by running these search strings was complemented by literature found by searching through their reference lists and bibliographies.

Selection Process

Papers were selected according to the inclusion/exclusion criteria defined in Table 1. Figure 1– based on the PRISMA four-phase flow diagram (Moher et al., 2009) – is utilised to highlight the selection process used in this systematic review, which was carried out by the main author of this review.

Table 1. Inclusion and exclusion criteria.

	Inclusion criteria	Exclusion criteria
1.	Published in or after 2008	Published prior to 2008
2.	Published in English	Published in a language other than English
3.	Article published in a peer-reviewed journal	Article not published in a peer-reviewed journal
4.	Full text copy of article available	Full text copy of article not available
5.	Article focuses on MASS and challenges related to their safety	Article does not focus on MASS and challenges related to their safety
6.	Search terms were used in the setting/for the meaning they were intended	Search terms were used in other setting/for other meanings
7.	Non-duplicate study	Duplicate study

After the completion of the selection process, the 14 studies presented in Table 4 remained and were included in the qualitative synthesis.

Table 2. Search strings and results in four databases.

Database	Search string	Results
SCOPUS	(ALL (ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime* OR marine* OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND (merchant OR cargo) AND (safe*) AND (manag* OR overcom* OR challeng* OR system*)) AND PUBYEAR > 2007 AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))	779
Academic Search Elite via EBSCOhost	(ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime OR marine OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND safe* AND (manag* OR overcom* OR system* OR challeng*) AND (merchant OR cargo)	91
ScienceDirect	(ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime OR marine OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND safe* AND (manag* OR overcom* OR system* OR challeng*) AND (merchant OR cargo)	43
Web of Science	"TS=((ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime OR marine OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND safe* AND (manag* OR overcom* OR system* or challeng*) AND (merchant OR cargo))Refined by: LANGUAGES: (ENGLISH)Timespan: 2008-2018. Databases: WOS, KJD, MEDLINE, RSCI, SCIELO.Search language=Auto "	30

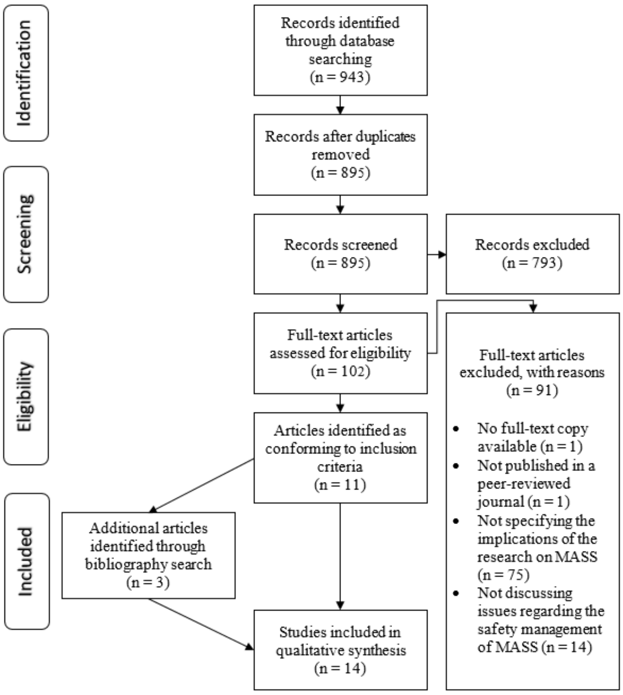

Figure 1. Flowchart of the selection process used in this systematic review.

Data Extraction

Data from the reviewed articles were manually extracted by the main author of this review. Principal data including author, year, title, country, design and outcomes are summarised in Table 4 below, while the identified safety challenges for MASS are discussed in more detailed in the results chapter.

Synthesis of Results

A narrative synthesis according to the guidance from Popay et al. (2006) was utilised in this review. The outcomes of the included studies and their methodological adequacy were described, explored and interpreted and when similarities emerged, they were be categorised as themes with explanations (Enya, Pillay, & Dempsey, 2018).

Quality Appraisal

The methodological quality of the identified studies that met the inclusion criteria were critically appraised using a set of screening questions utilised by Gillman and Pillay (2018), which were adapted from the Critical Appraisal Skills Programme (CASP) (Critical Appraisal Skills Programme, 2018).

The results of the quality appraisal and the risk of bias assessment can be obtained from (Dreyer, 2018).

RESULTS

Table 3. Main groups of challenges with sub-groups.

Main Groups	Sub-Groups
Technological	1. Hardware 1.1. Sensors 1.2. Communication 1.3. Fire Safety 1.4. Mooring 2. Software 2.1. Decision System 2.2. Software Errors 2.3. Cyber Security
Human Factor	1. Training 2. Effect of Technology on Human Operator 3. Human Centred System Design 3.1. Migration of Workplace 3.2. Presentation of Data
Procedural	1. Undesirable Events 1.1. Anticipated 1.2. Unanticipated 2. Standard Operations 2.1. Navigation 2.2. Maintenance 2.3. Cargo Care 2.4. Risk Assessment 2.5. Safety Controls 2.6. Absence of Regulations

Table 4. Characteristics and summary of reviewed articles.

Author(s)	Year	Title	Country	Design	Outcomes
Acanfora, M., Krata, P., Montewka, J., & Kujala, P.	2018	Towards a method for detecting large roll motions suitable for oceangoing ships	Finland, Poland, Italy	Case study	With the absence of seafarers on board, autonomous ships must have reliable methods for detecting critical operational conditions to be avoided. An alert must be raised when a roll motion starts to develop and an evasive manoeuvre must be executed immediately. This study therefore proposes a method providing for the avoidance of dangerous phenomena involving excessive motions of the ship.
Ahvenjärvi, S.	2016	The Human Element and Autonomous Ships	Finland	Exploratory	The paper highlights that the introduction of autonomous ships does not mean that there is no more human element involved in the navigation process and explores a number of select human factor issues that could be challenging in the safety management of autonomous ships.
Burmeister, H.-C., Bruhn, W., Rødseth, Ø. J., & Porathe, T.	2014	Autonomous Unmanned Merchant Vessel and its Contribution towards the e-Navigation Implementation: The MUNIN Perspective	Germany, Norway, Sweden	Exploratory	The development of advanced and integrated sensor systems for automated lookout, autonomous navigation systems incorporating the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs) and safe operation in harsh weather, a safe and reliable ship-to-shore communication architecture as well as human-centred design of onshore monitoring stations are regarded as central challenges for MASS.
Burmeister, H.-C., Bruhn, W., & Walther, L.	2015	Interaction of Harsh Weather Operation and Collision Avoidance in Autonomous Navigation	Germany	Case study	Challenges for MASS identified in this paper include the requirement to decide independently how to react to unfavourable weather conditions and how to avoid collisions in accordance with the COLREGs. It highlights cargo care, the transiting of dense traffic and coastal areas, and the large number of interconnected requirements and dependencies in the system as problematic, meaning that different requirements must not be resolved independently. It further highlights that misbehaviour or negligence of other vessels must be taken into account and that a MASS must be able to realise when a departure from the rules is necessary.
Ghaderi, H.	2018	Autonomous technologies in short sea shipping: trends, feasibility and implications	Australia	Exploratory	The paper concludes that new skills and competencies are required to design, build and operate unmanned vessels, and highlights challenges in maintenance, compatibility in navigation support systems and cyber security.
Hogg, T., & Ghosh, S.	2016	Autonomous merchant vessels: examination of factors that impact the effective implementation of unmanned ships	Australia	Exploratory	The paper argues that the belief in complete reliability and trustworthiness of automation on ships is unrealistic. Numerous challenges are identified, including in the area of communications, human impact, legislation and standardisation, procedures, cyber security, and maintenance and prevention of technological failure.
Man, Y., Weber, R., Cimbritz, J., Lundh, M., & MacKinnon, S. N.	2018	Human factor issues during remote ship monitoring tasks: An ecological lesson for system design in a distributed context	Sweden	Case study	This study came to the realisation that a control centre cannot just copy the design of a conventional ships bridge. Instead, it is argued that ecological interface design should be utilised in order to create a virtual ecology that reflects the constraints in the work domain and supports user-environment coupling.
Rødseth, Ø. J., & Burmeister, H. C.	2015	Risk Assessment for an Unmanned Merchant Ship	Norway, Germany	Case study	A number of challenges – combined with some possible solutions – were identified in this paper. Hazards related to the interaction with other ships, errors in detection and classification of small/medium sized objects, detection of objects in low visibility, propulsion system breakdown and heavy weather are highlighted as being challenging to the safety management of MASS as no reliable control mechanisms have been identified yet.

Author(s)	Year	Title	Country	Design	Outcomes
Thieme, C. A., Utne, I. B., & Haugen, S.	2018	Assessing ship risk model applicability to Marine Autonomous Surface Ships	Norway	Theoretical review	This paper highlights that there is currently no appropriate risk model for MASS, which is a challenge for their safety management in itself, because a clear concept of risk is necessary to describe, communicate and manage risk.
Wróbel, K., Krata, P., Montewka, J., & Hinz, T.	2016	Towards the Development of a Risk Model for Unmanned Vessels Design and Operations	Poland, Finland	Case study	The outcome of this paper is that the safety of an unmanned ship as a system is made up of several features, most of which must not be considered separately from others, as the failure of one of the ships' subsystem can trigger a chain of events leading to potentially catastrophic consequences. This is visualised in the Bayesian network they created, which describes relationships between safety issues pertaining to unmanned vessels.
Wróbel, K., & Montewka, J.	2018	A method for uncertainty assessment and communication in safety-driven design - a case study of unmanned merchant vessel	Poland, Finland	Case study	The paper allocates levels of uncertainties to risk mitigation measures. Identified areas with particular uncertainties are the involvement of the remote operators, software solutions and the potential for so-called black swans.
Wróbel, K., Montewka, J., & Kujala, P.	2017	Towards the assessment of potential impact of unmanned vessels on maritime transportation safety	Poland, Finland	Causal	The results of this paper reveal that the likelihood of an unmanned ship being involved in a navigational accident would decrease, while the extent of consequences – particularly from non-navigational accidents – can be expected to be much larger. Numerous challenges to be addressed in order to allow for the safe operation of unmanned ships are identified in the paper.
Wróbel, K., Montewka, J., & Kujala, P.	2018	System-theoretic approach to safety of remotely-controlled merchant vessel	Poland, Finland	Case study	The results of this study indicate that ensuring the safety of MASS shall consist of executing various controls on regulatory, organisational and technical plains. As most safety constraint violations can be attributed to technical issues, mitigation of many hazards can be achieved by introducing redundancy to safety-critical systems. Examples of areas that are inherently different to traditional ships are navigation, power generation, fuel management, cargo conditioning and fire safety.
Wróbel, K., Montewka, J., & Kujala, P.	2018	Towards the development of a system-theoretic model for safety assessment of autonomous merchant vessels	Poland, Finland	Case study	The results of this paper indicate that software development and validation appear to be the parts of the system that are hampered most by significant uncertainties regarding safety performance. By applying a system-theoretic process analysis hazard mitigation measures were identified that can improve the safety performance of MASS. As a result, this paper highlighted a number of challenges related to their safety management.

The review has identified three main groups of challenges, namely **technological** (addressed in 13 different reviewed studies), **human factors** (addressed in 13 different reviewed studies) and **procedural** challenges (discussed in 13 different reviewed studies). These main groups were further split into sub-groups as shown in Table 3 above.

Technological Challenges

This sub-section presents the identified technological challenges, which can be split up into hardware and software.

Hardware

This section presents issues relating to the hardware of MASS, specifically to sensors, communication equipment, fire safety installations, apparatus for rendering assistance and mooring systems.

Sensors

MASS must be provided with an adequate sensor system capable of measuring a variety of different data available on-board. The importance of relevant sensors becomes apparent when looking at the consequences of their inadequacy. Due to the lack of "first-hand multi-sensory experience of a living person" (Hogg & Ghosh, 2016), a failure in the sensory system of a MASS would lead to it becoming blind, inevitably leading to it being unable to perform safely and efficiently (Wróbel, Montewka, & Kujala, 2018b). Such an inadequacy of the sensor system could be caused by "sensors' failures, installed sensors' inability to measure a required feature, unsuitable sensors being installed or their sub-optimal performance" (Wróbel et al., 2018b), which are all risks that must be addressed.

The literature generally distinguishes between sensors for sensing the environment outside the vessel (Burmeister, Bruhn, Rødseth, & Porathe, 2014; Burmeister, Bruhn, & Walther, 2015; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme, Utne, & Haugen, 2018; Wróbel, Krata, Montewka, & Hinz, 2016; Wróbel, Montewka, & Kujala, 2018a; Wróbel et al., 2018b), and sensors that measure the current state of the vessel (Burmeister et al., 2015; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b). The following critical areas in which adequate sensor data must be ensured have been identified: Lookout (Burmeister et al., 2014; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b), external environmental data (e.g. meteorological and oceanographic) (Burmeister et al., 2015; Wróbel et al., 2018a, 2018b), internal stability data (e.g. motion and stress) (Burmeister et al., 2015; Wróbel et al., 2018a), and internal system data (Wróbel et al., 2016; Wróbel et al., 2018a, 2018b).

Lookout data refers to any data used for the observation of the sea for hazards, other ships, land, wreckage and distress signals, and is used to prevent collisions and detect persons in distress. When lookout data is combined with external environmental data such as depth readings from the echo sounder, an image of the external environment of the vessel can be constructed. However, to ensure safe navigation, internal stability data must be gathered and analysed as well. By combining external environmental data and internal stability data, dangerous situations that could lead to loss or damage to the ship or its cargo can be either anticipated and avoided, or realised and corrected.

Internal system data refers to data taken from the different internal systems on board, e.g. machinery data, fire sensor data and data to evaluate damage to the ship.

Communication

Another hardware challenge related to the operation of MASS is their communication capability. The reviewed literature generally agrees that the communication architecture of a MASS must be safe and reliable and distinguishes between two different types of communication: "Ship-to-shore" (Burmeister et al., 2014; Ghaderi, 2018; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b), and "ship-to-ship" (Burmeister et al., 2014; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme et al., 2018).

The architecture of the communication system of a MASS is critical for both safety and security (Wróbel et al., 2016) and requires specialised systems with sufficient redundancy and backup operations (Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2018a). It must be ensured that MASS are provided with the necessary hardware to ensure reliable communication both with the remote control centre (Hogg & Ghosh, 2016; Thieme et al., 2018) and the monitoring and navigational systems used in ports (Ghaderi, 2018), even in regions where only restricted satellite bandwidth is available (Burmeister et al., 2014).

Means for communication with conventional vessels must also be provided (Hogg & Ghosh, 2016), which may prove to be challenging as this type of communication must be catered to humans on the bridges of the conventional vessels.

The uncertainties in the capabilities of the current technical communication solutions available lead Wróbel et al. (2018b) to conclude that communication – which is considered to be a major part of the whole system – requires further study.

Fire Safety

Depending on the type of MASS, the design of a technical system capable of preventing or handling fires in all possible scenarios was identified by Wróbel, Montewka, and Kujala (2017) to be an extremely difficult challenge. However, as major subsystems of a MASS are heavily reliant on one another, the performance of such a fire protection system has a direct impact on the vessels machinery systems and navigational capabilities (Wróbel et al., 2016). Therefore it is concluded that MASS fire safety must be carefully addressed (Wróbel et al., 2018a).

Rendering Assistance

MASS may find themselves in a situation where they have to assist another vessel. They must be able to assist in the distress response and be able to pick up and accommodate survivors even in the absence of on-board crewmembers (Wróbel et al., 2016; Wróbel et al., 2017).

Mooring

Seven reviewed papers expect MASS to have a crew on board for the port-related activities, including departure and approach (Burmeister et al., 2014; Burmeister et al., 2015; Ghaderi, 2018; Rødseth & Burmeister, 2015; Wróbel et al., 2017, 2018a, 2018b). In case a MASS operator plans to enter port without having any crew on board, special mooring infrastructure must be provided (Hogg & Ghosh, 2016; Thieme et al., 2018). Such mooring equipment must ensure a safe mooring process for both the ship itself as well as any shore personnel involved in the operation.

Software

The identified challenges regarding the decision system of a MASS, potential software errors and ensuring cyber security are presented in this section.

Decision System

A number of challenges have been identified regarding the decision system that will need to be installed on a MASS designed with a navigation automation system. The two challenges that have been discussed the most is the ability of a MASS to avoid collisions with other traffic in accordance with the COLREGs (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016; Man, Weber, Cimbritz, Lundh, & MacKinnon, 2018; Rødseth & Burmeister, 2015; Wróbel et al., 2018b), and the ability to avoid and react to unfavourable weather conditions (Acanfora, Krata, Montewka, & Kujala, 2018; Burmeister et al., 2014; Burmeister et al., 2015; Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel et al., 2017).

The primary challenge is to ensure that MASS operate in compliance with the COLREGs. This has been fundamentally questioned by Hogg and Ghosh (2016) as they consider MASS as being incapable of mimicking the foresight a human navigator has on the bridge of a conventional vessel. As such, it must be ensured that good seamanship practice is replaced by methods and criteria (Acanfora et al., 2018; Wróbel et al., 2018b) sufficient to ensure that MASS can comply with the COLREGs.

While the COLREGs theoretically apply to all vessels upon the high seas (International Maritime Organization, 1972), misbehaviour or negligence of other vessels sometimes results in them not being applied in practice. The decision system of a MASS must therefore be able to avoid collisions with other vessels regardless of whether they follow COLREGs or not (Burmeister et al., 2015; Rødseth & Burmeister, 2015).

Another important part for ensuring safe navigation of MASS is the availability of reliable methods for detecting critical operational conditions that need to be avoided, both while planning the route and while monitoring the vessels progress along it (Acanfora et al., 2018). If a MASS encounters rough weather (Burmeister et al., 2014; Burmeister et al., 2015; Wróbel et al., 2016; Wróbel et al., 2017) or conditions that induce excessive motion and/or acceleration, her safety can be compromised.

It must be ensured that scenarios that can lead to damage of the ship or its cargo are determined both at the route planning stage and during the voyage execution stage (Acanfora et al., 2018). Detection of a potentially dangerous situation during the route planning stage should lead to the route being amended so that potentially dangerous sea areas are avoided (Acanfora et al., 2018), similar to how rough weather is avoided by utilising weather routing (Burmeister et al., 2015; Rødseth & Burmeister, 2015). During the voyage, the identification of a potentially dangerous situation should lead to the execution of mitigation actions, such as a change in course and/or speed and the raising of an alert to the controller (Acanfora et al., 2018).

When looking at the two challenges discussed above (i.e. reacting to traffic and reacting to environmental influences), it is highlighted that they cannot be resolved independently, as the required actions may be contradicting each other at times (Burmeister et al., 2015). Decisions made by one system module will inevitably have an effect on another. An example of such an effect is the need for a new route to be provided by the planning module if the control module of the MASS decides that it is necessary to deviate from the initially planned route (Acanfora et al., 2018). It is therefore essential that a holistic approach is adapted when designing the decision system in order to ensure the collaboration of the different components of the system (Wróbel et al., 2018b). As the proper functioning of the decision system depends on the quality of the input data (Wróbel et al., 2016), a stage where the quality of external- and sensor data is evaluated must be included in the system. Situations in which the indications of two or more sensors contradict each other must be identified and resolved in order to ensure the safe operational conduct of MASS (Wróbel et al., 2018a).

Further challenges that must be resolved are which action a MASS should take when all available options lead to undesirable outcomes, and ensuring that a MASS can adapt to unforeseen situations (Ahvenjärvi, 2016).

Software Errors

Even though the reliability and efficiency of the software utilised in MASS is of great importance to safety (Thieme et al., 2018; Wróbel et al., 2018b), there is a high probability that software errors will be present in their control system (Ahvenjärvi, 2016). This is considered to be a main risk for MASS (Rødseth & Burmeister, 2015). Proper software development and testing is therefore considered to be critical (Ahvenjärvi, 2016) and the introduction of technical standardisation, certification and inspection of the control system is encouraged (Hogg & Ghosh, 2016). Highlighted challenges are the revealing of software errors that are connected with abnormal situations (Ahvenjärvi, 2016) and the reduction of errors by reducing system complexity (Rødseth & Burmeister, 2015). Due to the presence of control algorithms in a large number of MASS system components, a lot of work needs to be done in this area (Wróbel et al., 2018a).

Cyber Security

Cyber security is considered critical for the safe operation of MASS (Ghaderi, 2018; Hogg & Ghosh, 2016). While virtually all system components are at risk of an attack (Wróbel et al., 2018a), the communication- and the information technology have been particularly highlighted by Ghaderi (2018). As devastating consequences may be expected if a breach in cyber security occurs (Wróbel et al., 2017, 2018b), ensuring the cyber security of MASS poses a major challenge that must be addressed appropriately.

Human Factor Challenges

The second group of identified safety for MASS are those related to human factors. This group is made up of challenges related to training, the effect of technology on the human operator, and human centred system design.

Training

Ensuring that all persons required to work with the new technology are adequately trained is mentioned as a challenge in a six different studies reviewed in this study (Ahvenjärvi, 2016; Ghaderi, 2018; Hogg & Ghosh, 2016; Man et al., 2018; Wróbel et al., 2018a, 2018b). The challenge to ensure proper training is not limited to seafarers (Ahvenjärvi, 2016) and shore-based operators (Wróbel et al., 2018b), but extends to naval architects (Ghaderi, 2018), technicians and engineers (Hogg & Ghosh, 2016) as well.

While Man et al. (2018) do not specifically state adjusted training requirements for MASS operators as a challenge, they do highlight that the required competencies of these operators have not been defined in regulations and that not enough research has been carried out on this topic. Hogg and Ghosh (2016) agree that new skills will be required and acknowledge the absence of regulation in this regard, but also highlight the importance of seagoing experience and question how the MASS operator of the future will gain the first-hand experience necessary to become an experienced Master when there are no more opportunities to work at sea.

As the implementation of operational trainings may have a positive effect on the influence humans have on the safety of MASS, ensuring proper training is of utmost importance (Wróbel et al., 2018a).

Effect of Technology on the Human Operator

None of the papers reviewed suggest that the implementation of MASS will remove the possibility of human error altogether, but the effect that humans will have on MASS has been discussed to a different extent. While Burmeister et al. (2015) and Ghaderi (2018) suggest that the introduction of MASS holds the potential to ultimately decrease human error, Ahvenjärvi (2016), Burmeister et al. (2014), Hogg and Ghosh (2016), Man et al. (2018), Rødseth and Burmeister (2015), Thieme et al. (2018), Wróbel et al. (2016), Wróbel and Montewka (2018), Wróbel et al. (2017), Wróbel et al. (2018a) and Wróbel et al. (2018b) argue that human factor issues will continue to be of significant importance in MASS operations.

The reviewed literature identifies a number of challenges related to the human factor that need to be managed in order to ensure MASS safety:

- Automation-induced complacency results in the operator being unable to detect malfunctions in the system, and is directly affected by the training received, the reliability of the system and the workload experienced (Hogg & Ghosh, 2016). If the operating system of a MASS is reliable, it is likely that the operator becomes over-confident in the system and loses vigilance. This negative effect of automation on the human operator has also been discussed in (Man et al., 2018; Wróbel et al., 2018a).

- Remote supervisory control may lead to out-of-the-loop syndrome (Man et al., 2018) and together with the lack of human connection to the MASS and absence of cues in an office-like environment may result in limited situational awareness of the remote operator (Ghaderi, 2018; Hogg & Ghosh, 2016; Man et al., 2018; Wróbel et al., 2018a), thereby possibly increasing the likelihood of an accident occurring (Wróbel et al., 2017). Furthermore, this leads to the inability for the operator to take over control in cases where the automation fails (Man et al., 2018) and has caused Hogg and Ghosh (2016) to question the effectiveness of the concept of supervising a MASS from a remote control centre altogether. This question gains more significance because humans are – due to their nature – not suitable for acting as a backup in human-automation interactions (Man et al., 2018).
- It is expected that the cognitive demands in the remote control centre will be higher than on the bridge of a conventional vessel (Hogg & Ghosh, 2016). If improperly managed, this may lead to information overload of the controller (Ghaderi, 2018). It is therefore considered essential that operators are kept at optimal mental work load levels (Hogg & Ghosh, 2016). In this regard Man et al. (2018) suggest if the pre-processing of raw data and flow may aid in reducing the demand of an operators cognitive resources.
- Another negative side effect of MASS implementation is the skill degradation of those charged with their remote supervision (Hogg & Ghosh, 2016; Wróbel et al., 2018a). Necessary steps must be taken to ensure that the remote operator will retain his or her skills in order to be able to take over control of the MASS when the situation so requires.

Human Centred System Design

Where the operator of a MASS is not stationed on board, the complete migration of the workspace away from the ship to must be duly considered in the design of the control centre. The presentation of data in a user-friendly way will be a challenge regardless of the location of the operator.

Migration of Workplace

One of the main results of the work of Man et al. (2018) is the realisation that the ecological changes related to the migration of the working place away from the ship must be considered when designing the remote control centre. The design of the technology in the control centre must be shaped for the new task of remote control and monitoring, meaning that current systems and practices cannot simply be transferred to the new location (Man et al., 2018). Ignoring the relationship between user and environment when designing the control centre may result in workplaces that are not suited for remote supervisory work and increase the gap between the demands of the work domain and the capabilities of the operator (Man et al., 2018).

Presentation of Data

A substantial amount of interaction between the MASS and its operators may be required at certain stages of a voyage (Thieme et al., 2018). Adapting a user-centred approach results in presenting the necessary data to the user according to his or her goals, tasks and needs (Hogg & Ghosh, 2016) will likely reduce the chance of him or her misinterpreting the data (Wróbel et al., 2017).

Utilising user-centred design in human-machine interfaces allows the operator to gain and maintain situational awareness (Ahvenjärvi, 2016; Thieme et al., 2018). Furthermore, it must be ensured that the data required by the operator is presented to him or her in all operating conditions, including unanticipated undesirable events. It is in these situations that automation functions may not reveal the true state of the system and provide the least help to the operator (Man et al., 2018). A central alarm management system including prioritisation of issues (Burmeister et al., 2014) may aid an operator in these cases, as he or she may not be able to make decisions due to information overflow and/or bad prioritisation of tasks (Wróbel et al., 2017).

Procedural Challenges

The final group of identified challenges is related to procedures, which is related to both undesirable situations and standard operations.

Undesirable Events

MASS can potentially experience undesirable events that have either been anticipated in advance (and therefore have contingency plans in place), or not.

Dealing with Anticipated Undesirable Events

It has been noted in the reviewed literature that even when considerable efforts are expended into ensuring excellent design and performance of MASS, it is likely that at some point a disaster might occur (Wróbel et al., 2017). A number of anticipated undesirable events have been identified in the literature. It is important that suitable measures will be in place to cope with these contingencies.

- Remote operators of MASS must anticipate the possibility of communication disconnections and ensure that suitable safeguards are in place in order to cope with such a situation (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel & Montewka, 2018; Wróbel et al., 2018a, 2018b). Fail-to-safe-functionalities that could potentially act as such safeguards have been discussed in (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2018a).

- Ahvenjärvi (2016) identifies the situation of multiple and simultaneous sensor faults as a particularly challenging situation for autonomous ships. In fact, the failure of any of the technological equipment on-board the MASS must be addressed in order to prevent minor technological failures from causing an error chain that may lead to an accident (Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b).
- While the consequences of a marine accident involving a conventional vessel are usually reduced by the actions of on-board crew, an unmanned MASS will have to rely solely on the available technology to respond to an accident (Wróbel et al., 2018b). As operators will be unable to make necessary manual adjustments themselves (Wróbel et al., 2018a), the accident response relies heavily on the ability to anticipate potential accident scenarios in the design stage (Wróbel et al., 2016), as this will decide the response mechanisms that will be provided. While it has been stated that damage assessment and control is likely one of the biggest challenges for MASS, previous studies have not accounted for the possible absence of humans on board when evaluating response options to MASS accidents (Wróbel et al., 2017).

Dealing with Unanticipated Undesirable Events

If a MASS runs into an unanticipated undesirable situation, the operator must be alerted in due time. Suitable alert points must be defined in order to ensure that he or she has sufficient time before the situation develops to a point where nothing more can be done to remedy the situation (Hogg & Ghosh, 2016; Wróbel et al., 2016). Due to the unanticipated nature of the undesirable event, this will be a challenging task.

Regarding the accident response of an unmanned MASS, the presence of black swans – which are scenarios that for some reason have not been analysed – must be anticipated (Wróbel & Montewka, 2018; Wróbel et al., 2018a). As it is next to impossible to account for all potential accident scenarios in the design stage, MASS should be designed in a way that ensures a proper level of resilience (Ahvenjärvi, 2016; Wróbel et al., 2017, 2018b).

Standard Operations

The introduction of MASS will have a considerable impact on a number of standard operations, and numerous procedural challenges to ensuring safe operations of MASS have been identified in the reviewed literature. They have been categorised as challenges regarding navigation, maintenance, cargo care, risk assessment, safety control and absence of regulations.

Navigation

In the case of a MASS controlled or supervised from a remote control centre the following challenges regarding navigation have been identified.

- Utilising the traditional hierarchy of a conventional vessel in a remote control centre may not be suitable. Hogg and Ghosh (2016) argue that assigning the captain as the final decision-maker may not be a suitable solution, as he or she will be out of the loop and have difficulty developing proper situational awareness in an emergency. The shift from conventional navigation to MASS operation must therefore be based on a review of manned bridge procedures (Burmeister et al., 2015).
- The interaction between the operator and the MASS varies depending on the level of autonomy. Procedures must therefore be in place to ensure a safe transition when the operator takes control of the MASS (Wróbel & Montewka, 2018), and that the system and the operator are able to adapt quickly to the new operational mode (Thieme et al., 2018).
- As MASS will continue to coexist alongside other vessels in the foreseeable future, it has been suggested that aspects such as the interactions between conventional ships and MASS must receive more attention in the future (Thieme et al., 2018). One such interaction may be the dangerous utilisation of predictable MASS behaviour by conventional vessels, as humans who have regular contact with automated systems have a tendency to create new and risky habits (Ahvenjärvi, 2016).
- Thieme et al. (2018) argue that current navigational aids are designed to assist human navigators, and argue that further investigation is necessary to assess if they need to be changed in order to facilitate MASS navigation.

Maintenance

The absence of a crew on board an unmanned MASS leads to the realisation that there will be no one on board to carry out maintenance while the vessel is at sea (Ghaderi, 2018; Hogg & Ghosh, 2016; Thieme et al., 2018; Wróbel et al., 2018b), causing a number of maintenance related challenges (Wróbel et al., 2017). A rigorous preventive maintenance scheme must therefore be developed to ensure that no maintenance of ship components is necessary while the unmanned MASS is at sea (Burmeister et al., 2014; Thieme et al., 2018; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b). As non-complex hardware problems can propagate and cause major problems (Rødseth & Burmeister, 2015; Wróbel et al., 2016) it must be ensured that sufficient backup solutions are available in case of a sub-system failure (Thieme et al., 2018).

Depending on the approach chosen to ensure that no maintenance needs to be carried out at sea, a number of different challenges have been identified in the literature. Hogg and Ghosh (2016), Thieme et al. (2018) and Wróbel et al. (2018b) declare that all MASS components will require extreme reliability. Any maintenance required will have to be carried out in port by specialised personnel (Ghaderi, 2018; Hogg & Ghosh, 2016; Thieme et al., 2018), introducing new implications for both port and ship operators (Ghaderi, 2018). It is even suggested that unmanned MASS will require new propulsion concepts, as conventional diesel engines are in need of frequent maintenance (Thieme et al., 2018).

Cargo Care

Current designs of MASS suggest that only cargo with low management requirements (i.e. stable, non-hazardous cargo that requires no maintenance or monitoring during the voyage) will be carried on unmanned MASS (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016). However, this view is not shared across the reviewed literature. Wróbel et al. (2016) can see issues arising from self-heating or self-igniting cargo, which suggests that they assume that such cargoes may be carried on board unmanned MASS. Wróbel et al. (2018b) are more direct assuming that more challenging cargoes can be accommodated if MASS are provided with the right functionalities. It should be noted that even if hazardous cargo was banned from being transported on unmanned MASS, undeclared dangerous cargoes may still end up on board (Wróbel et al., 2017). Safety issues regarding the carriage of hazardous cargo must therefore be addressed (Wróbel et al., 2017).

Risk Assessment

A number of the reviewed articles focus specifically on assessing the risk and uncertainty involved in MASS operation and highlight the difficulty in establishing a reliable risk model (Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2016; Wróbel & Montewka, 2018; Wróbel et al., 2017, 2018a, 2018b). However, a clear concept of risk is necessary to describe, communicate and manage risk (Thieme et al., 2018), and make feasible safety recommendations (Wróbel & Montewka, 2018). A number of key challenges that need to be overcome are outlined below:

- There is a widespread uncertainty regarding MASS in general, which means that reliable information regarding their actual design and operating circumstances is not available (Wróbel et al., 2016; Wróbel & Montewka, 2018; Wróbel et al., 2017). However, such information must be available if a generic and comprehensive risk model for MASS is to be developed (Thieme et al., 2018).
- Risk models in shipping have traditionally been quantified based on accident and incident data. However, due to absence of such data in a MASS context, such an approach is not viable for MASS risk models (Thieme et al., 2018). Furthermore, there is no empirical data pertaining to their performance (Wróbel & Montewka, 2018; Wróbel et al., 2018b), and areas that need special attention in the context of MASS operations have rarely been covered in depth in the literature (Thieme et al., 2018). If this absence of reliable data leads to incorrect assumptions, the assessment may lead to unjustified conclusions and incorrect decisions (Wróbel & Montewka, 2018). Circumventing this problem by utilising an existing model to assess risk is also described as questionable (Wróbel & Montewka, 2018).
- The concept of black swans described previously also has direct effects on the risk assessment models for MASS, as the likelihood of incomplete data leads to uncertain outcomes (Wróbel & Montewka, 2018; Wróbel et al., 2018a).
- Due to a lack of an officially defined acceptable risk level, the outcome of the existing risk models cannot be suitably utilised to assess MASS safety (Wróbel et al., 2016; Wróbel et al., 2017).

Safety Controls

Ensuring suitable safety controls systematically from higher organisational levels ensures that hazards are controlled at each point of the system structure (Wróbel et al., 2018a). However, mitigating hazards does not only involve the provision of safe control actions; it must also be ensured that those safety controls are applied at the right time and for the right period of time, and that they are applied in the correct sequence (Wróbel & Montewka, 2018; Wróbel et al., 2018a).

A further challenge is to ensure that safety and cost-effectiveness are suitably balanced (Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel et al., 2018a), as the reduction of cost is one of the most important arguments for MASS (Ahvenjärvi, 2016; Ghaderi, 2018; Rødseth & Burmeister, 2015; Wróbel et al., 2017, 2018a).

Absence of Regulations

Due to the absence of a regulatory framework regarding the many aspects involving MASS (Hogg & Ghosh, 2016; Man et al., 2018), it must be ensured that suitable operational procedures are available, relevant training is being organised and that the maintenance of on-board systems is properly managed (Wróbel et al., 2018a).

CONCLUSIONS

As mentioned in Banda et al. (2018), much technological research has been done regarding MASS. A great example is the push for satellite-based high-speed internet that is being developed by several major companies to reduce the likelihood of communication failure with MASS (Coldewey, 2019). However, with increased availability and reliability on internet communication systems, Ghaderi (2018) has identified cyber security as "the biggest challenge facing the maritime industry". The likelihood of unauthorised control of the ship can only be drastically reduced if proper design of communications, position sensing and on-board control systems is ensured (Rødseth & Burmeister, 2015).

A very real concern for MASS operations lays in the decision system, with "real-time intelligent algorithms for collision avoidance combining multiple vessel situations, dynamic weather conditions and COLREGS compliance is yet to be developed" (Hogg & Ghosh, 2016, p. 218). This is further complicated as the requirements of the COLREGs are sometimes open to interpretation (Vartdal, Skjong, & St.Clair, 2018). An obvious example of this is rule 6 of the COLREGs, which requires vessels to "proceed at a safe speed" (International Maritime Organization, 1972), without quantifying what is meant by the term "safe speed". MASS compliance with the COLREGs is therefore reliant on smart methods and criteria (Acanfora et al., 2018; Wróbel et al., 2018b) that have not been developed yet and therefore warrant further research.

Finally the realisation that humans are – due to their nature – not suitable for acting as a backup in human-automation interactions (Man et al., 2018) results in a challenge that need to be overcome if MASS are designed to be supervised from a remote control centre.

REFERENCES

Acanfora, M., Krata, P., Montewka, J., & Kujala, P. (2018). Towards a method for detecting large roll motions suitable for oceangoing ships. *Applied Ocean Research, 79*, 49-61. doi:10.1016/j.apor.2018.07.005

Ahvenjärvi, S. (2016). The Human Element and Autonomous Ships. *TransNav: International Journal on Marine Navigation & Safety of Sea Transportation, 10*(3), 517-521. doi:10.12716/1001.10.03.18

Banda, O. A. V., Ahola, M., Gelder, P. H. A. J. M. v., & Sonninen, S. (2018). *The need for systematic and systemic safety management for autonomous vessels*. Paper presented at the International Maritime Design Conference 2018, Helsinki. https://www.researchgate.net/profile/Osiris_Valdez_Banda/publication/325810203_The_need_for_systematic_and_systemic_safety_management_for_autonomous_vessels/links/5b264cc1a6fdcc697469e292/The-need-for-systematic-and-systemic-safety-management-for-autonomous-vessels.pdf

Burmeister, H.-C., Bruhn, W., Rødseth, Ø. J., & Porathe, T. (2014). Autonomous Unmanned Merchant Vessel and its Contribution towards the e-Navigation Implementation: The MUNIN Perspective. *International Journal of e-Navigation and Maritime Economy, 1*, 1-13. doi:10.1016/j.enavi.2014.12.002

Burmeister, H.-C., Bruhn, W., & Walther, L. (2015). Interaction of Harsh Weather Operation and Collision Avoidance in Autonomous Navigation. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 9*(1), 31-40. doi:10.12716/1001.09.01.04

Coldewey, D. (2019, May 14, 2019). SpaceX kicks off its space-based internet service with 60-satellite Starlink launch. Retrieved from https://techcrunch.com/2019/05/14/spacex-kicks-off-its-space-based-internet-service-tomorrow-with-60-satellite-starlink-launch/

Critical Appraisal Skills Programme. (2018). CASP Systematic Review Checklist. Retrieved from https://casp-uk.net/wp-content/uploads/2018/01/CASP-Systematic-Review-Checklist_2018.pdf

Dreyer, L. O. (2018). *Identified Challenges in the Safety Management of Merchant Maritime Autonomous Surface Ships: A Systematic Review of Scientific Journal Publications.* (Master Thesis). University of South-Eastern Norway,

Enya, A., Pillay, M., & Dempsey, S. (2018). A Systematic Review on High Reliability Organisational Theory as a Safety Management Strategy in Construction. *Safety, 4*(1). doi:10.3390/safety4010006

Ghaderi, H. (2018). Autonomous technologies in short sea shipping: trends, feasibility and implications. *Transport Reviews*. doi:10.1080/01441647.2018.1502834

Gillman, M., & Pillay, M. (2018). *An Integrative Literature Review: What Are the Barriers that Stop Organisations from Learning the Lessons Highlighted in Serious Incident Investigations?* Paper presented at the AHFE 2017 International Conference on Safety Management and Human Factors, Los Angeles.

Hogg, T., & Ghosh, S. (2016). Autonomous merchant vessels: examination of factors that impact the effective implementation of unmanned ships. *Australian Journal of Maritime & Ocean Affairs,* *8*(3), 206-222. doi:10.1080/18366503.2016.1229244

Convention on the International Regulations for Preventing Collisions at Sea, (1972).

International Maritime Organization. (2018). IMO takes first steps to address autonomous ships. Retrieved from http://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-MASS-scoping.aspx

Man, Y., Weber, R., Cimbritz, J., Lundh, M., & MacKinnon, S. N. (2018). Human factor issues during remote ship monitoring tasks: An ecological lesson for system design in a distributed context. *International Journal of Industrial Ergonomics, 68*, 231-244. doi:10.1016/j.ergon.2018.08.005

Maritime Safety Committee. (2019). Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS) - Proposal for terms to be avoided, recommended terms and draft of glossary. In International Maritime Organization (Ed.), (Vol. MSC 101/5/4).

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol, 62*(10), 1006-1012. doi:10.1016/j.jclinepi.2009.06.005

Popay, J., Roberts, H., Snowden, A., Petticrew, M., Arai, L., Rodgers, M., . . . Duffy, S. (2006). *Guidance on the Conduct of Narrative Synthesis in Systematic Reviews*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.178.3100&rep=rep1&type=pdf

Rødseth, Ø. J., & Burmeister, H. C. (2015). Risk Assessment for an Unmanned Merchant Ship. *TransNav: International Journal on Marine Navigation & Safety of Sea Transportation, 9*(3), 357-364. doi:10.12716/1001.09.03.08

Thieme, C. A., Utne, I. B., & Haugen, S. (2018). Assessing ship risk model applicability to Marine Autonomous Surface Ships. *Ocean Engineering, 165*, 140-154. doi:10.1016/j.oceaneng.2018.07.040

Vartdal, B. J., Skjong, R., & St.Clair, A. L. (2018). *Remote-Controlled And Autonomous Ships in the Maritime Industry*. Retrieved from https://www.dnvgl.com/maritime/publications/remote-controlled-autonomous-ships-paper-download.html

Wróbel, K., Krata, P., Montewka, J., & Hinz, T. (2016). Towards the Development of a Risk Model for Unmanned Vessels Design and Operations. *TransNav: International Journal on Marine Navigation & Safety of Sea Transportation, 10*(2), 267-274. doi:10.12716/1001.10.02.09

Wróbel, K., & Montewka, J. (2018). A method for uncertainty assessment and communication in safety-driven design - a case study of unmanned merchant vessel. *International Journal of Safety Science, 02*(01), 104-114. doi:10.24900/ijss/0201104114.2018.0301

Wróbel, K., Montewka, J., & Kujala, P. (2017). Towards the assessment of potential impact of unmanned vessels on maritime transportation safety. *Reliability Engineering & System Safety, 165*, 155-169. doi:10.1016/j.ress.2017.03.029

Wróbel, K., Montewka, J., & Kujala, P. (2018a). System-theoretic approach to safety of remotely-controlled merchant vessel. *Ocean Engineering, 152*, 334-345. doi:10.1016/j.oceaneng.2018.01.020

Wróbel, K., Montewka, J., & Kujala, P. (2018b). Towards the development of a system-theoretic model for safety assessment of autonomous merchant vessels. *Reliability Engineering & System Safety, 178*, 209-224. doi:10.1016/j.ress.2018.05.019

Immersive Virtual Reality in Marine Engineer Education

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***Abstract* - As simulation and computing technologies advance, new pedagogic opportunities are enabled which can add value to student learning outcomes. This study examines simulator training in maritime education comparing the emerging state-of-the-art technology of Immersive Head Mounted Display (HMD) Virtual Reality (VR) and Non-immersive 3D Desktop Virtual Reality desktop simulators. Two student groups from an undergraduate marine engineering programme completed identical tasks related to starting up a fuel oil separator in one of the two conditions: (*i*) Non-Immersive 3D Desktop VR (*n*=5), and (*ii*) Immersive HMD VR (*n*=6). After the experimental scenario the participants were given a memory power test to address differences in memory accuracy between the two simulator types. A significant difference was found in accuracy of memory which diverges between the groups with the Non-Immersive 3D Desktop VR group scoring lower than the Immersive HMD VR group. These results provide empirical evidence for the value of Immersive HMD VR simulators for marine engineering education.**

Keywords
Memory, Knowledge, Simulator Training, Maritime Education, Shipping.

INTRODUCTION
The human element, as an agent within the maritime industry, is developing along with technology towards a vivid complexity of human-machine interaction. Interdependency between new technology and the human element drive the demand for progressive technology development and require the human capital to obtain a new state of knowledge.

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The complex sociotechnical systems that a modern vessel now comprise of tend to put technical requirements in the centre of design, engineering and operation, rendering the human element to adapt and cope with the rest through interaction (Norman & Stappers, 2015). As operations move towards higher degrees of automation, regulatory complexity and cost (Mallam, Nazir, Sharma, & Veie, 2019), training and education for personnel must adapt.

Purpose of research
The research question investigated in this study is if Immersive Head Mounted Display (HMD) Virtual Reality (VR) simulator training is be the better technological solution for training declarative knowledge in maritime education.

The hypothesis tested predicts that declarative knowledge accuracy, by measurement of the power test, will be larger with the Immersive HMD VR simulator, shown in Figure 1, than with the Non-immersive 3D Desktop Virtual Reality (3D VR) simulator, shown in Figure 2.

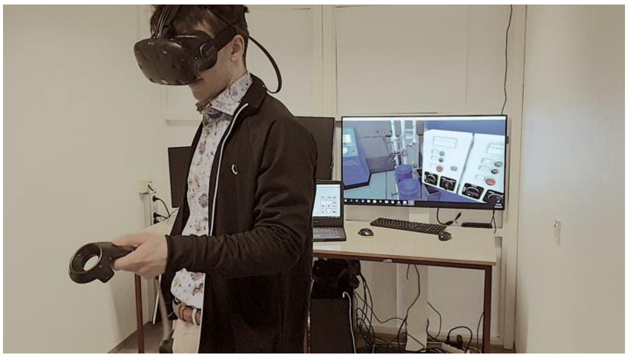

Figure 1: Participant engaged in the immersive HMD VR simulator condition. The screen in the background display a projection of the participant's view.

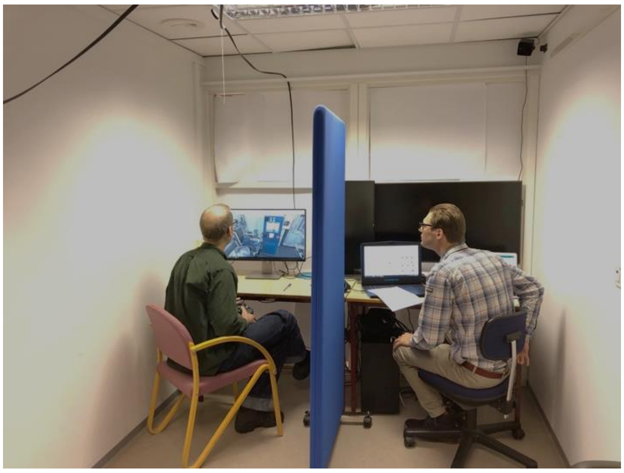

Figure 2: A participant in the non-immersive 3D VR simulator condition to the left. The instructor is at the instructor station to the right.

BACKGROUND

Simulators in Maritime Education and Training

Commercial simulators designed for maritime training emerged to public dissemination in the late 1970´s and developed to be embedded in the education of both marine engineer officers and nautical officers. Norcontrol which later would be Kongsberg Maritime, delivered their first analogue engine room simulator (Figure 3) in 1978. Simulators are used to train real life proficiencies in an environment safe from errors and play scenarios of extremes to practice performance of real-life environments (Sellberg, 2017).

Figure 3: The Norcontrol analogue diesel engine simulator delivered to Trondheim Maritime College in 1978 (Kongsberg Maritime, 2019).

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers by the International Maritime Organization (2016) sets the governing requirements for simulators and discriminates between the purpose of training and the purpose of assessing competence. The convention allows simulators to be used for training and assessment of novice seafarers in education and on-board training, and in revalidation of certificates for professional seafarers (A-I/11 & A-I/12, International Maritime Organization, 2016). This convention structures the industry by defining the main competences required for each discipline and rank, some of which partially can be trained and assessed with simulators.

Virtual reality

After decades of 2D desktop simulators, the field of marine engineering education is now saturated with Big View Desktop and 3D Full Mission simulators as the established commercial training solution. 3D Full Mission is a simulator type replicating both the full engine control room and engine room using monitors, touch screens and equipment where the interaction with the environment is visually and audibly animated in 3D. VR is an emergent technology developing with increasing momentum, for example Kongsberg Marine´s K-SIM Engine simulators as is used in this study.

VR has been advertised for decades to revolutionize simulator-based education, where new skills can be practiced through correction, repetition and safe failure in an inexpensive environment representing reality (Jensen & Konradsen, 2018). Immersive HMD VR differs from all non-Immersive VR where the user views the simulated environment from an outside position, e.g. through a traditional desktop display. Immersive HMD VR technology exchanges the natural sensory input with digitally generated sound and vision, enabling the user´s brain and nervous system to behave as if present in a real environment (Jensen & Konradsen, 2018).

Immersion

Advancing the development one step further from the non-Immersive 3D VR environment, introduce the enhanced experience of full immersion. Though not currently available commercially, Immersive HMD VR simulators are of interest to maritime simulator developers. With Immersive HMD VR technology, the environment surrounds the user with an egocentric self-to-object view, which discriminates the immersive experience from the non-immersive 3D VR and all previous generations of simulators. The non-immersive 3D VR desktop depicts an egocentric vision; however, interaction is allocentric object-to object as the user view the environment through a monitor. This allocentric interaction is also the denominator with previous generations such as CAVE systems, Big View desktop and 2D desktop. With stereoscopic graphics through the HMD, visual updating by the user's head movement and direct interaction through hand controllers makes the experience more immersive and realistic (Freina & Ott, 2015).

forming a knowledge test, one should be particular in designing the format as different tests measure different underlying constructs of Figure 4.

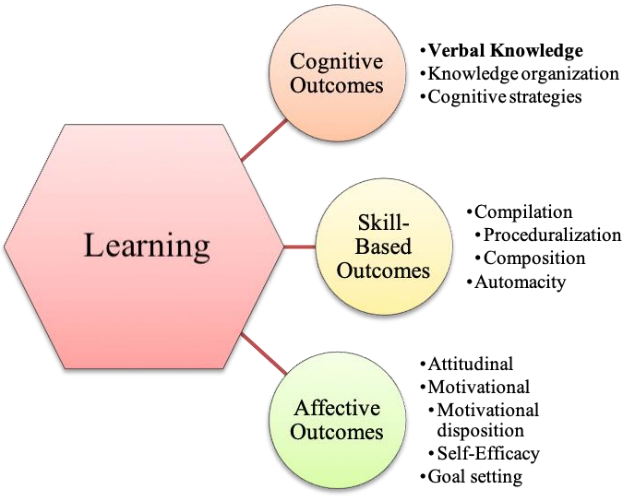

Figure 4: Model of learning outcomes adapted from (Kraiger et al., 1993).

Naturally individual differences will affect and form a group score. The underlying constructs measured by these various knowledge tests are influenced by differences connected to individual general intelligence, which can be decomposed into abilities such as fluid intelligence, crystalized intelligence, spatial abilities, perceptual speed abilities, psychomotor abilities and more (Ackerman, 2014). As general intelligence factors seem to be critical for novel task performance, trainees competent at inferring relations and memorizing information will show success in early training. Through further exercise and experience this between-subject gap will close towards a stage of procedural knowledge as behaviours become internalized and psychomotor differences affect performance as much as intellectual capabilities in task performance (Kraiger et al., 1993).

On measuring declarative knowledge in its traditional form during training, Kraiger et al. (1993) argue that these tests should be given at an early stage in the training, as the feedback is necessary to identify the knowledge gap that might inhibit the consecutive higher level learning, such as converting to procedural knowledge and developing tacit knowledge unbiased of false knowledge and expectations. Further implications for repeated measurement is that since variance in declarative knowledge will be greater at the beginning of training than at the end, higher scores measured early is more beneficial for predicting other learning outcomes (Kraiger et al., 1993).

Learning outcomes

Traditionally, the fields training and education have focused on changes in verbal knowledge or behavioural capacities as learning outcomes (Kraiger, Ford, & Salas, 1993). Bloom (1956) proposed that there are cognitive learning outcomes beyond recollection and recognition of verbal knowledge in his taxonomy of learning. Gagné (1984) later argued that this taxonomy should include various cognitive, skill-oriented, and affective learning outcomes. Adapting and refining this, Kraiger et al. (1993) proposed their new framework for training evaluation and the assessment tools needed to capture the various learning outcomes. Confining to the cognitive learning outcomes of the framework, this category is built with a taxonomy of verbal knowledge, knowledge organization and cognitive strategies. As the cognitive learning outcomes are not only a static state of knowledge, evaluation and training evaluation also have to consider the dynamic process of knowledge acquisition, organization and application. Knowledge organization and Cognitive strategies, which underlying learning constructs are mental models and metacognitive skills falls beyond the scope of this study.

Declarative knowledge

Verbal knowledge comprises of declarative knowledge, procedural knowledge and strategic or tacit knowledge (Kraiger et al., 1993). Declarative knowledge is information about facts, semantics and rules, and is easy to write, teach or test (Norman, 2013). Knowledge of rules doesn't ensure people will abide them and knowledge about facts don't have to be true, we only store sufficient knowledge to do tasks and don't need further precision in our judgements (Norman, 2013).

Measurements of knowledge

Evaluating declarative knowledge is in line with how institutions today evaluate their subjects, where their acquisition of declarative knowledge is examined through multiple-choice, true-false, free recall or recognition tests (Kraiger et al., 1993). At a higher level of evaluation, speed tests measure within a given time, and power test measure correctly answered items given unlimited time (Kraiger et al., 1993). Power tests measure accuracy of stored information from memory and have traditionally ignored errors and focused on correct items answered (Ackerman & Ellingsen, 2016), these tests should be used when the consequences of errors are high and accuracy is valued (Kraiger et al., 1993). Speed tests will measure the speed of processing information and is hard to correct for guessing, to account for this, speed tests to measure fluid intelligence are designed incrementally harder for each item to discriminate at which level consistent answering disrupts. When

Effects on training

Webster (2016) investigate declarative knowledge acquisition with Immersive HMD VR on soldiers, and in accordance with similar studies, he found that the immersion has a positive effect on the learning outcome compared to lecture-based instruction. In their review of studies on immersive HMD VR training, Jensen and Konradsen (2018) found that lecture-based instruction is better for remembering facts while an immersive learning environment is better for spatial and visual knowledge. Further they found no research that have examined training of higher-level cognitive skills with immersive HMD VR.

Passig (2015) investigates immersive HMD VR as training medium of cognitive skills, they can conclude that while some cognitive skills deteriorate in the population over time, others emerge. Though some research now find average IQ scores, as now measured, to decline, we might be in an erratic evolutionary process we simply cannot comprehend or measure at this time (Passig, 2015). In summary, they conclude that human mental capabilities in fact are improving, though it is not absolute certain they do so solely through advanced technology, by stimulus-filled environments or both. Not only does advanced technology such as Immersive Virtual Reality improve abstract cognitive skills as supposed by Flynn (2018), concrete cognitive skills improves as well according to Passig (2015).

METHODS

This study followed a classic experimental design with two groups for between group measures. The design was chosen as the participants could not conduct both conditions due to the potential carry-over effect. The treatment was designed to be as similar as possible in both the immersive HMD VR simulator and the non-immersive 3D VR simulator.

The pre-test was developed by the authors to capture the subject's semantics and system knowledge of the machinery operated in the treatment. The post-test consisted of a memory power test developed by the authors to capture accuracy of the students' knowledge acquisition.

The hypothesis stated that a measure of the post-test with the two student groups would be different with the two simulator types. The random group assignment is the independent variable as the two different conditions could cause different outcomes. The power of memory by our post-test after the treatment is the dependent variable, measured as a retention of knowledge acquired.

The study was approved by the Norwegian Centre For Research Data (NSD), project file number 188181.

Experimental setup

All experiments and data collection were conducted in the quiet and ventilated VR Lab at The University of South-Eastern Norway. For both simulator conditions, the instructor station was assigned to a monitor in the lab with the 2D process interface. In the non-immersive 3D VR condition (Figure 2), the instructor also had view of the monitor used by the participants, while a partial wall inhibited the participants from viewing the instructor and his monitor. The instructor administered the same station for the immersive HMD VR condition (Figure 1) where another monitor show the visuals from the HMD as the participants were immersed in the scene.

Participants

The sample frame consisted of two student groups recruited from the second year of the marine engineer programme. The students were randomly assigned to either a (*i*) Non-immersive 3D VR desktop group (n=5) or an (*ii*) Immersive HMD VR group (n=6) based on their voluntary booking time for the experiment. All participants were males.

Table 1:Group demographics

Group		(i) 3D VR	(ii) IVR
	n=	5	6
Age	Mean	28,40	22,67
	SD	12,66	0,82
Professional Experience	Mean	0,60	0,17
	SD	0,89	0,41

Intervention

An exercise of starting up a fuel oil separator, as shown in Figure 5, was chosen for the treatment task. This was chosen as it is an important machinery system focused on in the education programme, as well as during sea service. A fuel oil separator produces a purified quality fuel oil to the daytanks and is often designed with redundancy for safe operation, as the lack of fuel oil transferring options or clogged fuel supply can induce main engine shut-down situations. At the time of the research, this machinery had been covered in the marine engineering programme through lecture-based instruction. Though the immersive HMD VR simulator and the non-immersive 3D VR desktop simulator had slightly different limitations in their replication of the real-life equipment, the exercise was formulated to match both simulator conditions.

Figure 5: The fuel oil separator system of the immersive VR simulator

Treatment

Compared to the 2D process control interface of the instructor station as shown in Figure 6, both simulator conditions had missing elements, such as valves or gauges. These elements were only visually missing in the participants' simulator environment, and had no implication to the treatment procedure as their function were included in the actual simulator programme of the 2D process control interface controlled by the instructor.

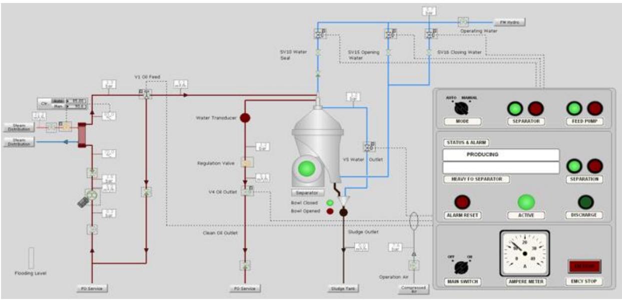

Figure 6: 2D process control of the fuel oil separator of the K-SIM Engine simulator as viewed from the 2D Desktop option.

The 2D process control monitor is the equivalent to the ship´s Integrated Automation System (IAS) were the duty engineer officer remotely operate and monitor the machinery from in the engine control room. This is also the interface of the simulators that both students and instructor would use when operating the simulator system as a 2D desktop option.

In the Immersive HMD VR simulator (Figure 1), participants could move freely by walking in the simulator environment, only bounded by the physical walls of the VR Lab. Physical displacement within the VR Lab, enacted an equivalent movement in the virtual reality environment. Since the virtual environment was larger than the laboratory a locomotion technique called teleportation was used for moving further in VR environment. All interaction with the simulator systems was administered through the hand controllers (Figure 7).

In the non-immersive 3D VR desktop simulation (Figure 2), the environment comprised of the full engine room of a container. The participants sat in front of the desktop monitor, enacted movement and interaction through the Microsoft XBOX hand controller (Figure 8).

The task in the treatment was to conduct a starting operation of the fuel oil separator system from a shut-down condition with a procedure created by the authors (Table 2). A brief system description, a flow chart diagram copied from the 2D process control interface (Figure 6), and the task description with procedure (Table 2) was given on paper for 10 minutes to the participants to review and internalize before withdrawn again and commencement of the treatment. Within this 10-minute review prior to the treatment, the participants could ask the instructor to clarify eventual uncertainties found. The treatment was timed, observations on task sequencing and performance was noted by the instructor. If participants felt stuck between procedure steps or uncertain about system statuses which could not be read in the environment, they were allowed to ask the instructor for help.

Table 2: Task Procedure

1	Switch on electricity and set local operating panel in Manual mode.
2	Line up all valves on the oil system. Open valves for heating steam, operating air and operating water.
3	Start oil feed pump and check that heat regulation and three-way oil feed return valve is ready.
4	Start separator. Monitor amperemeter during speed ramp up.
5	When amperemeter drop, switch local operating panel control to Auto.
6	Adjust throughput by throttling back pressure valve from fully open position and ensure correct production.

Materials

Equipment

For both immersive VR and desktop 3D VR simulator interfaces, an Alienware 15 R3 laptop computer with the K-SIM ENGINE software was used. The laptop computer had a 2.9GHz Intel Core i7 processor and 16GB RAM memory with the Windows 10 Pro operating system. An engine room simulator of a reefer container vessel (Kongsberg Digital Mak 8M43CM11) was used in the study.

Figure 7: HTC VIVE head mounted device, and hand controllers of the immersive VR simulator

For the immersive HMD VR simulator, a HTC VIVE VR system was used (Figure 7). For the non-immersive 3D VR simulator, the participants interacted with the simulator through a 27” desktop monitor and a wireless Microsoft Bluetooth XBOX controller (Figure 8). The instructor station was set up with a 2D process control (Figure 6) monitor and a partition wall between the participant and the instructor where the instructor had view of the participant´s desktop monitor as shown in Figure 2.

Figure 8: The Microsoft XBOX hand controller of the 3D VR simulator.

Measurement Instruments

The pre-test consisted of an assessment of initial learning through a recognition test developed by the author. On cognitive skill acquisition, Anderson (1982) states that at least 100 hours is required to gain any significant degree of proficiency, more than the students would have spent on this specific system but way less than time spent on learning and training machinery systems in general.

In the pre-test, a process flow chart from the Figure 6 display was assigned 20 numbers to the systems main elements. A table with the label names of these 20 elements was included and the participants was asked to assign the correct element number from the process flow chart to the corresponding label name of the table. The task was tailored to be at a difficult level, though without a time limit logic reasoning should provide a score. To close any knowledge gap and mitigate the effect of individual aptitudes, feedback was given on the incorrect answers. This was an important design feature as identification and awareness of the main elements was considered essential for performance in the treatment and on the post-test.

The post-test consisted a memory power test to assess accuracy and accessibility of retaining knowledge acquired in the treatment. No time limit was set to ensure the test was measuring accuracy and not processing speed of mental computation. Accuracy of memory is a more valid construct to train and test when the consequences of error is high (Kraiger et al., 1993). Memory power test usually focus on correct items answered and neglect the incorrect; to give the power of memory an additional dimension, incorrect items answered was also considered in accordance with Ackerman and Ellingsen (2016).

The post-test was on the same paper sheet as the 20-item pre-test; the participants were asked to mark off the elements they recall that were missing from the simulator environment. The non-immersive 3D VR simulator had 4 elements missing and the immersive HMD VR simulator had 8 elements missing. These elements could be valves or gauges expected to be present in a live system, and was present on the 2D flow chart given prior to the treatment. Correct items answered gave a score range of 4 and 8 respectively, and thus, incorrect items answered a range of 16 and 12. No admonitory indication of the post-test was given prior to the treatment. The measurement score was aggregated with range of the immersive HMD VR simulator as index, i.e. the 3D VR scores was multiplied with 2.

RESULTS

The hypothesis predicted that declarative knowledge accuracy, by measurement of the power test, would be larger in the Immersive HMD VR group (*ii*) than in the Non-immersive 3D VR desktop group (*i*). The Table 3: Descriptive statistics show a quite even prerequisite knowledge from the pre-test.

The post-test correct scores resulted as predicted were the Non-immersive 3D VR desktop group (*i*) scored lower than the Immersive HMD VR. For the inferential statistics the Mann-Whitney *U* test was used and had a significant difference in medians U=0, Z=-2.796, P=0.005, r=-0.843.

The post-test incorrect scores gave an insignificant Mann-Whitney *U* test with difference in medians U=7.5, Z=-1,447, P=0.148, r=-0.436.

The gains the post-test correct scores are significantly different with a large effect size and the post-test incorrect score is insignificant and with a medium effect size.

Table 3: Descriptive statistics

Group		(i) 3D VR	(ii) IVR
Pre-test score	Mean	19,00	18,17
	Median	20,00	18,00
	SEM	0,63	0,65
Post-test correct score	Mean	0,80	5,33
	Median	0,78	5,00
	SEM	0,49	0,42
Post-test incorrect score	Mean	-0,80	-1,67
	Median	0	1,50
	SEM	0,80	0,56

DISCUSSION

The pre-test was a recognition test on identification of system items. As the pre-test scores were relatively even between the groups, this strengthen the post-test results as independent of the former, but might induce a question of necessity regarding the pre-test feedback element in the experiment design. While designing the experiment, the pre-test was expected to give a larger margin of error, rendering the feedback element necessary for a standardized commencement of the treatment. Still evaluated as valuable to the design, the pre-test holds no prediction of consecutive learning outcomes, only a probe of the prior knowledge base and the feedback a uniform standard before the experiment commencement.

The two types of simulators show an effect of different knowledge acquisition with the same population and the same knowledge base. Immersion has shown to be a positive factor for knowledge acquisition (Webster, 2016), and the hypothesis might hold evidence accordingly. The difference found between the simulators might be a factor from their environments, whereas the non-immersive 3D VR desktop simulator is encompassing with a complete engine room environment and the immersive HMD VR simulator is relatively confined to a single room. Observations during the experiments led the author to note an incidental tendency to digress from the task in both simulator conditions. As the more encompassing environment of the non-immersive 3D VR simulator has higher level of details and other systems, its effects (Towler & Kraiger, 2008) are possibly an influencing factor on the lower score of the (*i*) non-immersive 3D VR desktop group. It is likely to believe that the two different environments, or their means of interaction, require or facilitate a different level of mental computation. One observation that is difficult to leave unmentioned; all (*i*) 3D Virtual Reality desktop group participants that scored 0 on the post-test forfeited the attempt to recall the experience effortlessly.

Accepting the hypotheses acknowledges the prototype immersive HMD VR simulator as superior to the commercial non-immersive 3D VR desktop simulator, based on the design of this study.

The research question investigated in this study was if immersive VR simulator training was a more effective technological solution for training declarative knowledge in maritime education for a specific marine engineering task. As far as this study's result show, there are advantaged to implementing immersive VR in the educational programs. An appropriately designed simulator and training programme should achieve to supplement students with facets of knowledge and skills the present 2D desktop simulators and the Non-immersive 3D Virtual Reality desktop simulators cannot offer.

Future Research

Further developments of the two simulators demand development of task designs that might enhance learning outcomes with both interfaces. As both simulator technologies are relatively unexplored in marine engineering education, there is a lot of uncovered ground for research. Training higher-order cognitive skills (Figure 4) such as mental models and metacognition are unexplored with immersive HMD VR, and there are opportunities in maritime education for designing training programs approximating these constructs with resources management, safety training and team exercises. With new technology and new simulators there is always the opportunity for training effectiveness studies of the established training programs, and development of new ones as the governing regulations regarding training are quite flexible to exercise designs. Regulations of assessment schemes are more explicit, thus studies of competence assessment with Immersive Head Mounted Display Virtual Reality is necessary both before and after a quality standard approval of the simulator.

With the two simulators as is, the consecutive response to this preliminary study would be to focus effort on a training scheme with repeated measures with an untainted new cohort of second year students. Task specific exercises with marine engineering students over a semester or two and a final assessment of competence could be designed with training in the non-immersive 3D Virtual Reality desktop simulator and assessment in the Immersive Head Mounted Display Virtual Reality simulator. Another group could be trained in the Immersive Head Mounted Display Virtual Reality simulator and assessed on real life equipment. As the participants of this study has advances to their final year of the marine engineering program, a repeated measure could be taken to measure knowledge retention, or a new and more complex task design with performance indicators to evaluate the technology as an assessment tool

Limitations

The clinical environment of the Virtual Reality Lab and presence of researchers in the room during data collection may have influenced the participant's performance and results. A segregated instructor station or remote supervision of the experiments could mitigate these effects. However, this was not a practical option for this study of this experimental design.

As there is only one undergraduate programme in marine engineering within Norway, the only solution to strengthen the sample frame would be to recruit students enrolled in the marine engineer programs at the vocational college level, or expand the research to international institutions.

CONCLUSION

This study found a difference between the accuracy of memory between the non-immersive 3D Virtual Reality desktop simulator and the immersive Head Mounted Display Virtual Reality simulator. These results provide empirical evidence for the value of immersive Virtual Reality simulators for marine engineering education.

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REFERENCES

Ackerman, P. L. (2014). Nonsense, common sense, and science of expert performance: Talent and individual differences. *Intelligence, 45*(1), 6-17. doi:10.1016/j.intell.2013.04.009

Ackerman, P. L., & Ellingsen, V. J. (2016). Speed and accuracy indicators of test performance under different instructional conditions: Intelligence correlates. *Intelligence, 56*, 1-9. doi:10.1016/j.intell.2016.02.004

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89*(4), 369-406. doi:10.1037/0033-295X.89.4.369

Bloom, B. S. (1956). *Taxonomy of educational objectives: the classification of educational goals: handbook i* (Vol. 16).

Flynn, J. R. (2018). Reflections about intelligence over 40 years. *Intelligence, 70*, 73-83. doi:10.1016/j.intell.2018.06.007

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education- state of the art and perspectives. *The 11th International Scientific Conference on eLearning and Software for Education Bucharest, 1*, 133-141.

Gagné, R. M. (1984). *Learning outcomes and their effects: Useful categories of human performance* (Vol. 39).

International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) : including 2010 Manila amendments ; STCW Convention and STCW Code, (2016).

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *The Official Journal of the IFIP Technical Committee on Education, 23*(4), 1515-1529. doi:10.1007/s10639-017-9676-0

Kongsberg Maritime. (2019). Kongsberg Maritime History. Retrieved from https://www.km.kongsberg.com/ks/web/nokbg0237.nsf/AllWeb/03E4EADBA358FC78C1256A55004648C0?OpenDocument

Kraiger, K., Ford, J. K., & Salas, E. (1993). Application of Cognitive, Skill-Based, and Affective Theories of Learning Outcomes to New Methods of Training Evaluation. *Jurnal of applied psychology, 78*(2), 311-328. doi:10.1037/0021-9010.78.2.311

Mallam, S. C., Nazir, S., Sharma, A., & Veie, S. (2019). *Perspectives on Autonomy – Exploring Future Applications and Implications for Safety Critical Domains*, Cham.

Norman, D. A. (2013). The design of everyday things (Rev. and exp. ed. ed.). New York: Basic Books.

Norman, D. A., & Stappers, P. J. (2015). DesignX: Complex Sociotechnical Systems. *She Ji: The Journal of Design, Economics, and Innovation, 1*(2), 83-106. doi:10.1016/j.sheji.2016.01.002

Passig, D. (2015). Revisiting the Flynn Effect through 3D Immersive Virtual Reality (IVR). *Computers & Education, 88*, 327-342. doi:10.1016/j.compedu.2015.05.008

Sellberg, C. (2017). Representing and enacting movement: The body as an instructional resource in a simulator-based environment. *Education and Information Technologies, 22*(5), 2311-2332. doi:10.1007/s10639-016-9546-1

Towler, A., & Kraiger, K. (2008). The Effects of Seductive Details on Recognition Tests and Transfer Tasks. In I. N. Depaul Univ Greencastle (Ed.).

Webster, R. (2016). Declarative Knowledge Acquisition in Immersive Virtual Learning Environments. *Interactive Learning Environments*, *24*(6), 1319-1333. doi:10.1080/10494820.2014.994533

Siri, sail the ship! - Exploring human-RIA relationships in the maritime domain

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Abstract - **Imagine a teammate who always follows procedures, remembers everything, is alert at all times and needs neither sleep nor rest. You may be imagining a Robotic, Intelligent, Autonomous (RIA) technology, designed to form a specific type of relationship with you. The International Organization for Standardization (ISO, in press) proposes a set of design approaches for RIA technology that, when applied, result in various human-RIA relationships. The aim of this paper is to explore these relationships and to open up a discussion on human factors in future maritime settings. The method used is expert workshops, using prompts to focus the discussion of forecasting the future. The analysis shows that the beliefs and ideas of the experts point to many different types of human-RIA relationships in the imagined maritime future. Stakeholders might be unaware of the consequences of this system complexity. Therefore, we discuss the potential implications from a human factors perspective, including individual, team, organisational and social aspects.**

Keywords
Human-RIA relationships, automation, maritime future, human factors.

INTRODUCTION

This work explores a set of assumptions about the human role in complex and automated maritime systems, including those in which humans and Robotic, Intelligent, Autonomous (RIA) technology coexist and form dynamic relationships. Predicting the future is a task with a considerable probability of failure, but there is no doubt that we need a critical discussion around human factors in the future of shipping. Technology develops rapidly. Innovative solutions have the potential to revolutionize the status quo in a relatively short period. On the other hand, human-related areas like education, training and job organisation require more time to respond to change.

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Therefore, it is vital to take into consideration human-related issues at a very early stage of technology development. Currently there is a large number of autonomy-themed projects for maritime, for example MUNIN - Maritime Unmanned Navigation through Intelligence in Networks (http://www.unmanned-ship.org/munin), but few of them aim to address human factor issues as a main topic.

In a related paper we present plausible future scenarios for autonomous shipping based on outcomes of HUMANE project workshops (Lutzhoft, Hynnekleiv, Earthy, & Petersen, in press). This paper discusses the future roles of humans in the system. The analysis is focused on identifying topics that are important to the stakeholders with regards to the human role in high levels of maritime automation. We will discuss the consequences of these assumptions from a human factors perspective and offer guidance for enabling a systemic change.

This paper is organized as follows. The background introduces a framework for understanding how members of a sociotechnical system work together towards shared goals. In our approach, system members include humans as well as machines or software that can be defined as RIA. We also present an outline of human-RIA relationships. These provide basis for analysis of the stakeholder views and underlie the discussion on education and training prospects. Thereafter, we describe the methodology of this study. Next, we present the findings and locate them in the human factors framework. Finally, we discuss implications of, and enablers for, technological change in the maritime industry.

BACKGROUND

Sociotechnical systems

Sociotechnical systems theory focuses on interactions between social and technical elements of a system and specifies that these interactions decide the performance of system as a whole. In a simple system the interactions may be linear and predictable. However, with increasing complexity of the elements and the environment, interactions become more multi-faceted, interlinked and every-so-often unpredictable. *Sociotechnical systems* is a metaphor that expresses the sociotechnical systems theory. It refers to a system comprised of technical and social elements, whose activity is directed towards a joint goal (Walker, Stanton, Salmon, & Jenkins, 2008).

In this paper, we consider several future maritime scenarios, such as collaboration between seafarers located on board, highly automated ship technology, intelligent software agents, operators in shore centres as well as vessel traffic services. Thus, we consider a sociotechnical system not limited by space, but rather defined by emerging connections between its elements. Moreover, the borders of the system are fluid and can change dynamically based on which elements are involved at a given time.

Joint activity

Performing tasks in groups has been the focus of scientific discussion for many years. Most definitions of teamwork include team members, the relationships between them and a shared goal. For example, Sundstrom, De Meuse, and Futrell (1990) define teamwork as interdependent action by individuals who share responsibility for specific outcomes. However, in sociotechnical systems, team members are not only humans, but also RIAs. The teamwork literature typically does not include non-human members with the exception of *joint activity* theory (Mansson, Lutzhoft, & Brooks, 2017). In accordance with sociotechnical systems theory, we consider teamwork to be more than just the sum of individual activities performed by members of a sociotechnical system.

When framing discussions of human-technology collaboration, it is necessary to find inclusive concepts. **Teaming** appears to be a suitable candidate. *Human-automation teaming* is described in the literature as the dynamic, interdependent coupling between one or more human operators and one or more automated systems requiring collaboration and coordination to achieve successful task completion (Cuevas, Fiore, Caldwell, & Strater, 2007).

Human-RIA relationships

Developing RIA technology requires consideration of a broad range of influences and interactions on many levels. Human factors as a scientific domain must expand its scope to include the digital world. ISO (in press) describes a range of design approaches, which determine relationships between RIA and its users. An overview is presented in *Table 1*. Broader explanation and examples of the design approaches are included in the *Results*.

Connecting RIA technology with humans in one sociotechnical system can produce a range of issues, which need to be addressed by human factors. These issues are specific for RIA technology and fall into different categories. ISO (in press) identifies six groups of possible human-RIA issues, which scale up from individual level to broad, societal context (see Figure 1).

Table 1. Design approaches for RIA technology. Adapted from *Ergonomics — Ergonomics of human/system interaction — Part 810: Human/system issues of robotic, intelligent and autonomous systems, by* ISO/CD TR 9241-810.

Design Approach	Description
Augmentation	The system improves human performance
Replacement	The system replaces human functions and/or entire human jobs
Remoting	Allows the user to act on the physical environment at distance
Teaming	The human and machine work together for a common goal
Symbiosis	The human and the system are closely linked working together for mutual benefit
Parasitic	The human is a source of data collected by the system, but with little or no benefit to the human
Influence	Intelligent systems influencing human behaviour
Unknown	As yet undefined paradigms relating to organisational, social/cultural, societal relationships with RIA systems
Benevolent Governance	Humans/humanity passing governance to AI

Effects on humans

The first group characterises the impact of RIA technology on humans, at an individual level. This includes physical, cognitive, affective, behavioural and motivational effects that RIA can induce in humans. RIA can influence not only the humans it was designed for (users), but possibly also individuals accidentally or unexpectedly interacting with it (non-users).

Human-RIA system interaction

This category of issues refers to users, both individuals and teams, directly interacting with RIA. It covers the effect that the design of the RIA interface has on the users’ ability to accomplish their goals.

Multiple RIA systems interacting

Another group of issues is interactions between multiple RIA technologies as part of sociotechnical systems. The interaction may or may not be obvious to users. All the ways in which the interaction of multiple RIA technologies might affect users are not yet clear.

Organisational

RIA technology may affect the organisation as a whole, including changing of processes, roles and number of employees, communication and organisational culture.

Social/cultural/ethical

Technology is bringing extensive changes to society, and one can anticipate that effects of RIA will also spread within social and cultural context. What makes RIA different from any other technology is that it might not be viewed as inert matter, since it possesses characteristics that so far have been assigned only to humans. The behaviour of RIA must therefore be appropriate for the cultural context it operates in.

Emergent societal

The last category covers the wider consequences of RIA to society, including the allocation of responsibility and decision-making, credibility of algorithms and data use, and deterioration of human skills.

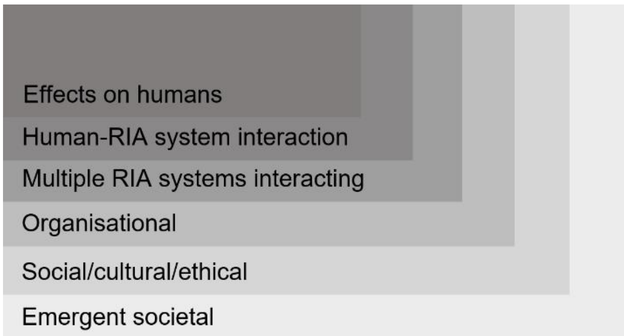

Figure 1. Categories of human-RIA issues. Adapted from *Ergonomics — Ergonomics of human/system interaction — Part 810: Human/system issues of robotic, intelligent and autonomous systems,* by ISO/CD TR 9241-810.

METHOD

The data was collected during two expert workshops on the following themes related to autonomous shipping: *System safety and cybersecurity* in October 2018 and *Legal, class and insurance* in January 2019. The workshops involved 42 experts in total who were invited according to their work experience and current expertise within these themes.

Additional data was collected during follow-up interviews with experts who were invited to workshops but could not attend, and with those who wished to discuss the topics further.

Table 2. Organisations represented by the participants of expert workshops.

CIRM	SINTEF	Inmarsat
Massterly	BW Gas	Wärtsilä
Rolls Royce	Bellona	MTI-NYK
DNV-GL	Lloyds Register	Kystverket
InterManager	ABB	Norcontrol
Kongsberg Maritime	Kongsberg Seatex	Maritime Robotics
F-Secure	RISE Viktoria	EXMAR
Norwegian Maritime Authority	Danish Maritime Authority	Swedish Transport Agency
Western Norway University of Applied Sciences	Norwegian University of Science and Technology	University of Southeast Norway
University of Southampton	Åbo Akademi University	Wilhelmsen Ship Management
BIMCO	Gard	

Procedure

The experts were divided into groups of 5-6, assuring that each group consisted of people from different sectors of the maritime industry. Each group had a moderator with academic experience, both in maritime and human factors. All the moderators were members of HUMANE research group. During the first expert workshop (*System safety and cybersecurity*) the moderators used the following set of application-based prompts to direct the discussion: *1. Unmanned bridge, 2. Unmanned engine room, 3. Ultra-low manning, 4. Shore monitoring/ support centre, 5. Remote control, 6. Fully autonomous.*

During the second expert workshop (*Legal, class and insurance*) the prompts were introduced in the form of questions: *1. Is it possible to keep to conventional regulations, and adapt the autonomous solutions? 2. What type of regulations are difficult to change, what is important to change? 3. What are the challenges in achieving change? 4. What can we do to address or mitigate them? 5. How does the future influence a perception of: (a) responsibility, (b) liability, (c) control, and (d) authority? 6. Who benefits the most from a goal-based approach to regulations?*

The focus of the two workshops was not human factors, but the topic was repeatedly raised by participants. Therefore, this paper focuses on humans and their relationship to RIA systems.

Analysis

Recordings of the workshops were transcribed resulting in 400 pages of transcription (verbatim, but excluding emotions, background noise, inaudible speech). The obtained text was anonymized by removing personal information of the participants. The transcript was imported into NVivo 12 Pro software and coded manually. Qualitative analysis was performed using thematic grouping and regrouping of coded fragments. The focus of the analysis was to examine the beliefs and opinions about the human role in future scenarios.

Design approaches to RIA technology were used as analytical categories for organizing and interpreting the data. None of the concepts were prompted during data collection or explicitly present in the data. We present the results of the analysis using the RIA design approaches as subheadings/categories.

RESULTS

Our intention is to show the views of the participating experts and the similarities and differences in opinion. We apply human factors concepts as categories of analysis and in exploring consequences for human role in complex sociotechnical systems. In this section, direct quotes from the expert workshops are written in italics and quotation marks. Contrary to traditional science papers, the results subsections include elements of discussion.

Augmentation

ISO definition: *The system improves human performance*.

One participant mentions improving the human lookout (a person on a ship whose task is to look out for other ships, objects, land etc.). The lookout is often positioned on the bridge. This role dates back to a time before electronic aids, and is still around – now as a complement to the technology. The need for a lookout is fiercely contested.

"Human enhancement, that can be in two dimensions. That could be in terms of breadth of what you see but also in terms of maintenance of vigilance over a longer period of time, or assisting with [remembering]."

The quote spans widely over human factors issues, enhancing perception and sensing (what you see), performance (vigilance) and cognition (memory). The participants discuss the possibility of augmenting human performance, and go on to criticising human abilities in comparison to machines.

"I would say that you can do lookout by machine much better than you do today. I mean, I have a lookout at bridge that haven't seen a tanker that's one mile away from you, that's completely useless."

Of note, the participants often mention augmentation and replacement in the same sentence. There seems to be an unspoken assumption that augmentation ultimately leads to replacement.

"Would it be possible to make the case that a technical lookout probably could be more efficient than a human lookout?"

This also illustrates the overlap between **augmentation**, **replacement**, and perhaps also **teaming**. Using watchkeeping as an example to illustrate this point, it would be defined as **augmentation** if the technology provided additional information to the watchkeeper by having an overlay of radar information in view from the watchkeeper window. An example of **teaming** would be to automate lookout and have the two independent systems (human and technology) 'discuss' what they see and have a collective situational awareness regarding the voyage plan and watch hours. In this case, the technology would need to be artificial intelligence rather than 'just automation'.

Replacement

ISO definition: *The system replaces human functions and/or entire human jobs*.

"No more human error on board" is a very common catchphrase. Unfortunately, it is interpreted to mean 'no more humans on board'. What do we win and lose by removing humans? How do the risks change?

"Humans are doing a lot of interpretation of the situation that we need to automate in the future."

The speaker is talking about how much information humans interpret in a complex environment. It is a skill to process information, which is not only based on experience and recognizing patterns, but on acting adequately upon unexpected, atypical events. The natural follow-up question is how much of this cognitive process we can automate.

Some participants discuss the unmanned bridge as the way to 'remove human error' from navigation. Furthermore, it is seen as a waste of resources to use a highly trained master to sail 'a straight line'. Instead, the crew could be used to do other work.

"On the positives we not [only have] a chain here. Well, human errors and unmanned bridge, you have the possibility to remove human error."

"I have more or less the same [view], it's a good start against unmanned or low manned solutions. Less human errors, better utilizing [of] resources."

"I think it's useless, having [a highly] trained captain [...] to shift when it's going [in a] straight line for six days. So you can utilize them in other way."

The appreciation for technology among participants seems strong, and sometimes leads to statements that pit the human against technology.

"If we are talking about autonomous ships, I think anybody who has appreciation for technology knows

that autonomous ship is likely to be much safer because of the lack of [the] human error element."

However, the discussion rarely addresses how well the technology can perform in atypical and ambiguous conditions, for example bad weather, time pressure or system failure. It is important to keep in mind that there is still no available data to suggest that automation will actually do better.

What **replacement** in easy conditions actually argues for is **teaming** where the crew hands over to the automation when it is safe to do so. Indeed, by removing humans, we do remove some risks, as the example of cyber security below shows.

"By taking the people away from [on] board you are actually also certainly lower the risk. […] I mean the person on watch, charging mobile on the ECDIS system at open USB port, he is in risk. The supplier, I mean the service operator coming from [Company] and plugging his laptop in the local network, he is part of the risk. If you can remove these people, you use part of this but you get other problems."

We also see awareness regarding new risks being introduced. Some of the participants comment on the human contribution to overall system safety, for example through interpretation skills. That brings us to back to the situation where 'humans interpret', for better or worse.

"Humans are also preventing a lot of incidents. In the car industry they are getting a little bit nervous because now authorities want to have the data. How many incidents do we actually have? Now we have sensors that can say how many situations we have in the traffic system and that are prevented by human. So maybe we see that humans save ten times more than the automation would do."

Humans of course have cognitive limitations. We do not have an endless supply of alertness and attention, we get tired, fatigued and bored. What is more, we need a job that is stimulating, rewarding and meaningful.

"*A lot of watch keeping is defined around the limits of human ability to stay awake and stay not bored."*

Limitations of human mind seem to point to a need for **augmentation** or **replacement**. However, these two approaches have different design goals. **Augmentation** should not be seen as a step towards **replacement** but a design goal in its own right and for its own benefits. If both **augmentation** and **replacement** are design goals then decisions need to be made about graceful degradation in performance and the handover between RIA and human needs to be designed.

Remoting

ISO definition: *Allows the user to act on the physical environment at distance*.

Will the control be performed from shore or another ship? Throughout ongoing projects, there is an apparent agreement that there will be a shore centre. We could also imagine remote control performed from another ship or maybe from on board the own ship. Very little is mentioned about the alternatives to shore centres. However, a considerable advantage of working ashore – we are not taking a stance on *who* does that work– is *being* ashore. This means working close to home and to family, friends and social environment. Working ashore brings the opportunity to have social interactions with people that one chooses to interact with.

"You don't need to be away from family, you can do a normal eight-to-five kind of life."

However, drawing a parallel to crew communication – seafarers used to have very little possibility to contact home (or anywhere ashore). It was argued that this would lead to crewmembers worrying about home instead of focusing on work – thus a potentially unsafe situation. Now that many more seafarers have better communication, they know what is going on at home. Now they know what to worry about. The comment below speculates that an operator working ashore is so 'close to home' that this risk might be even higher.

"I just called it situational awareness in order to you know, making people really aware of what is happening around and that as you say it's rather it's also other vessels and all this kind of stuff. Because not being there on the bridge physically but sitting in a comfortable office somewhere, it does something with your mindset and also I think you have to be even more forced into taking the situation in the account, because it's so easy to fall back in your own thoughts and in whatever is happening at home because you're like five minutes away from home. And it keeps calling, you know […] you're not on board of the vessel. It does something with you. I think."

Another aspect of the human factors of remote control and operation is the physical and mental distance between controller and the controlled entity. Many are concerned that it will feel like a video game, implying that the presence and engagement in a situation, normal or emergency, is not as focused as if the operator was on board.

"*Just thinking when you are sitting at shore centre. It will easily be like video games, because anyway, you will not have the feeling of the weather."*

"Well, I agree with you, the way you perceive danger and danger for the vessel, in terms of whether it would be different."

"What happens on the bridge is more than sensory detection."

Being on the bridge or on the ship provides a 'contextualized' feeling. In comparison to a shore centre, the data and information one receives and perceives are different. We already see this kind of effect with unattended engine rooms. There is a lack of willingness to leave the control room to check what the instrumentation is telling you, combined with a trust that all the sensors are working and in the right place to monitor the systems.

Remoting brings a problem of gaining experience and skills of ship handling, equipment and system management.

"Equipment awareness. I think that as time goes by, people are operating stuff from shore. That means that the equipment that you are controlling it is away from where you are. It makes this distance makes it also difficult for you to learn from the machines and what is going on. So it's kind of, how do we prevent it from becoming like a video game?"

When picturing what it would be like to be an operator at a distance, the absence of direct feedback could become very stressful and frustrating, even if one supposedly has control. This lack of control is described from the perspective of a seafarer – one who is used to perceiving much more contextual sensory input.

"You put him ashore and tell him "Here's a joystick and here's the screen and you can see a couple of numbers" he would go like "[expletive]... I don't feel the control, I don't feel the vibration, there's this smell missing, and the humidity is wrong and I don't know what the heck is going on here, I feel very insecure and I cannot do it". But if you take a video game on, smells, vibrations, I don't know what that is anyway, even if you give it to me, I don't know what to do with it. So you need a different operator."

Who is the person who will operate ships remotely? Should it be an experienced seafarer or highly skilled gamer? Our participants frequently discuss this issue, but there is no consensus on who the operator might be. It is also not clear which sensory inputs are vital and which are an instance of: 'we have always done it this way'.

Teaming

ISO definition: *The human and machine work together for a common goal*.

This sounds like the ideal case, and it is the concept getting the most attention from the human factors community (McNeese, Demir, Cooke, & Myers, 2018; Shively et al., 2017). The state of the art in technology and artificial intelligence is not at a point where we can talk about meaningful teaming for a complex operation.

The line between teaming and augmentation is blurred but many of the participants mention technology being a supportive 'team member', leading to a situation where the whole is larger than the sum of the parts. The discussion on increased automation does not focus on reducing the manning levels. But, in fact, the goal of highly automated system can be increasing safety and reducing workload.

"Now [work hours regulation] is very much strict so actually if we try to keep the same level of a number of crews [...] we are already overworked. So we would like to relax the workload. We can comply with [...] conventions and improve safety."

"In chess man plus machine beats machine. That's a good argument for having support. You can allow people to sleep at night, working dayshifts."

Does this constitute teaming or human augmentation? Can RIA be a new member of the crew, supporting the human operator? Many believe humans and machines should work together.

"*Collaboration with man and machine is better than either alone*."

The statement that **teaming** can produce better outcomes is particularly true if the machine is aware of the hours of work and rest. At the moment we have the 'low tech', whereas future 'high tech' may have the capability to interact in a social way.

"*Now technology has completely different capabilities in that area, it never gets bored, it never falls asleep, so how can we bring together the new things that technology can do and what humans are good at is making the best of a bad situation and suddenly bringing an awful lot of world knowledge to a particular situation, which a computer doesn't have and won't have for a long time*."

The automation needs knowledge of the world and experience of conditions. Being in a **teaming** situation means sharing workload and having the same situation awareness. To achieve this, RIA needs to provide information in a way that humans can perceive, understand, interpret and use it to make good decisions. Can this be designed?

"But if he haven't seen these conditions of multiple targets in dense fog, it takes a lot of practice and experience to build up and identify what's hostile and what's not. To get out of the cold and go to the unmanned bridge and he is not getting handover from

somebody, because there is nobody there. It's hard, I think, he's building situation awareness."

Technology will most likely need to learn:

"Most of these things will be some sort of confidence level. So it [technology] will say "Ok this is me looking around, I see some different objects, 99% percent sure that's a rock, I'm 99% sure that's a boat but there's this other thing out here I just can't classify it". So a human operator will say "All right that's a yacht" or whatever."

However, we must separate the teaching task and the navigation task. Adding the task of teaching the AI (knowledge engineering) to the watchkeeper's job constitutes added workload at a time and place where the watchkeeper does not need it. That could also create a peculiar situation of 'training your own replacement'.

Assuming a RIA being correctly trained, retrained, upskilled and updated, it will be changing its behaviour, function, and interaction. This will add complexity to the human-RIA teaming effort.

"They constantly evolve and the difference for the software system is that software is never done. It is always updated and changed. You never get that full-depth understanding of every single component and how it is interacting. You are managing this constantly changing thing."

Understanding automation is challenge enough, but when it is perpetually changing, the RIA must communicate and make itself understandable and transparent to human operators.

"Humans need to understand what the machine is doing. The machine has to show what it is going to do."

This would need to be a design goal – design for collaborative work and social exchange. This becomes even more important in the context of handing over the control.

"And then there is a space where the human might have to take control at some point. […] there is an efficiency gap between in takeover period. […] if you require humans to take over at some point, the efficiency drops dramatically until the human sort of catches up. […]"

In this team view, concepts like communication become important. In a handover situation, the human needs to understand what happened. The discussion also focuses on the time dimension. The speaker is assuming that the handover is abrupt and there is not much time available between event and handover, so the performance will drop until the human can 'catch up'. This issue should be addressed at design stage so the technology allows time for becoming fully engaged in the situation, either by being resilient, graceful degradation or by being 'always in control', as proposed by the MUNIN project (http://www.unmanned-ship.org/munin).

The interaction between man and machine becomes even more complex when we imagine larger systems.

"So we are all talking about decision power switching rapidly back and forth. Not just between machines and humans but between different humans and different machine systems."

The scenario is now highly dynamic and time critical. The imagined situation sounds almost impossible for a human to participate in. The speaker continues:

"And it leads me to think that perhaps there should be almost like a firewall between what people are doing and what machines are doing."

This dilemma currently appears to have two solutions. It is either complete separation of humans and 'robots' (for example cages for robots in factories, restricted zones or lanes for autonomous mining trucks) or finding a way to co-exist – a symbiosis.

Symbiosis

ISO definition: *The human and the system are closely linked working together for mutual benefit.*

Symbiosis can be viewed as an expanded form of teaming, where both human and RIA benefit from the interaction. Our participants imagine a situation where the human can be a source of data for improving RIA performance. If RIA experiences uncertainty, it can communicate with a human, for example presenting the levels of certainty and ask for appropriate instructions (see subsection **Teaming**). Thus, RIA can take an active learning role, even communicating its training needs:

"An AI don't know what to do: "When the wind conditions [are] like this, my code doesn't provide me with what seems to be a sensible choice. Can you, as a human, show me …?" And then that's used to generate more training data."

The comment is based on an assumption that in this setting the human can point to one action of choice that is 'sensible'. However, in complex environments there are often many choices of action, each with drawbacks and benefits. For example: a ship is docking, and the wind changes. Actions possible to manage the new conditions include changing the ship's speed, using a thruster, applying more or less rudder, propeller pitch or engaging a tug. Considering the complexity of the work environment, training the RIA would require the human to have a set of advanced skills. Also, unless training tasks and navigation tasks can be separated in time, the watchkeeper will experience increased workload.

For the relationship to be truly **symbiotic**, the human needs to benefit from it as well. In this case training the RIA would reduce human workload in the future, allowing the watchkeeper to focus on other tasks or to rest. Maintaining a **symbiotic** relationship requires trust between seafarers and providers in terms of the use of training data.

Parasitic

ISO definition: *The human is a source of data collected by the system, but with little or no benefit to the human.*

In a situation like the one presented in subsection **Symbiosis**, the human could be used unknowingly as a source of training data for the RIA. The line between **symbiosis** and **parasitism** is not well-defined when we consider long-term consequences of humans training the RIA technology. At the moment of interaction, the relationship can be beneficial for both sides, but in a wider perspective it could lead to replacing humans or using the data for commercial purposes without benefit for the data sources (De Stefano, 2018)

Influence

ISO definition: *Intelligent systems influencing human behaviour*.

This category assumes influencing human behaviour in an intentional way by RIA technology. In the maritime context, it could translate to evaluating human actions and providing guidance. However, this design approach does not correspond with the collected data.

Benevolent governance

ISO definition: *Humans/humanity passing governance to AI.*

This relationship matches the participants' vision of fully autonomous systems, which are completely independent and self-regulating.

"[...] we are [...] really inventing this, you know, vacuum tube. You put something in, you press the button and it arrives at the other end. That's what we are trying to do."

How involved will the humans be, and is it the (hidden) agenda to eventually design humans out of the system?

"This is all about integrity of the system, the system tells us but we are the humans actually setting the rules for this."

"I think we will even see decision support systems that [are made] for the human at first. In order to get confidence. This is the evolution."

This approach to design seems to solve a range of problems with human-RIA interaction, simply because there will be no interaction. However, the participants do not imagine **benevolent governance** to be implemented as a design approach in the foreseeable future. The main problem is the immaturity of artificial intelligence and a lack of ways to verify and validate it.

"I think AI have a come in, in order to do what humans are doing, I mean, it's hard to break us down into algorithms. Like individual algorithms, manually, it has to be done more automatically. And that's why I think we need artificial intelligence to do it, and then we also need this test bed and verification. I don't think you can have approved AI, you can just do it, that's what you would do with a human, subject them to some tests. If you pass the test, you're ok."

However, there is no need for this design approach to be applied if it is not needed. After all, humans have a lot to contribute.

"Humans are also preventing a lot of incidents…so maybe we see that humans save ten times more than the automation would do".

DISCUSSION

This study has an exploratory character, and is about the future, and the vision of how the maritime future changes – when the HUMANE project started in 2018 the goal was understood to be unmanned, self-governing ships. The authors note that discussion at the IMO Marine Autonomous Surface Ships intersessional meeting 2-5th November 2019 indicates that focus has shifted from completely unmanned, fully autonomous ships to automation of functions associated with navigation

If we envision future ships to be manned, at least partially and to some degree controlled by humans, the design of such a system requires extensive reflection of human factors issues. Designing an effective and safe human-RIA system remains a challenge.

"It's relatively easy to build fully manual ship or fully autonomous. If you have to have man and machine with human in the loop, that's difficult."

The main barrier on the technological side is the immaturity of artificial intelligence. Its performance is satisfactory in limited contexts and structured environments. Most maritime work contexts does not match these criteria.

On the human side, many issues need to be addressed. By disregarding fundamental principles of human capabilities and limitations, we risk producing technologies that challenge or overload human operators (Fitts, 1951). This leaves the human to do the integration work (Lutzhoft, 2004) and be the 'glue' in the sociotechnical system.

The six categories of RIA technology issues (ISO, in press) also point to systemic challenges. For example, effects on individuals include trust issues connected to data usage and training the RIA for replacing the humans. On the RIA-human interaction level, there is the challenge of designing the RIA in a way that humans will be able to socially and professionally interact with. The choice of RIA design approach has significant influence on the organisation as a whole, redefining tasks and roles of its employees. Higher-level human-RIA system effects on society are still very much unknown.

If the maritime stakeholders decide to adopt or apply the design approaches, it should be pointed out that their purpose is not defining the task allocation. Relationships between RIA and humans are not static role designations, but a subject to dynamic changes. For example, RIA **replacement** of human functions may shift to human-RIA **teaming** if RIA is no longer able to cope alone due to unanticipated events. Sometimes the roles of humans and RIA may overlap, and we can expect incomplete or interrupted interactions as well, particularly in the early, experimental, stage of development. This means misunderstandings, delays, and other known human-machine challenges.

A limitation of the study is the fact, that our participants represent a predominantly Scandinavian perspective.

CONCLUSIONS

When discussing the future of maritime sociotechnical systems, there are various design approaches and relationships between humans and RIA to consider. It is not as simple as removing humans from the system (**replacement**) or moving them ashore (**remoting**). Even though the topics of the workshops concerned system safety and regulatory aspects, participants' comments implicitly relate to the RIA design approaches and consequential human-RIA relationships. Some of the design concepts may be considered new to the maritime sector, and some may be more relevant than others. Nevertheless, the findings provide a foundation for further exploration and discussion of the making of maritime human-automation systems.

For the time being, technology is not sufficiently mature to deal with complex environments and to form some of the discussed relationships with users. This applies in particular to systems where humans and RIA are 'partners'. The future choice of design approaches will affect individuals, teams, organisations and society in ways that we can only predict to a limited extent.

Finally, it is clear that resilient integrated solutions cannot be achieved by just adding new elements to the system. A human-centred approach is required to consider human factors in the design process and reflect on human capabilities and limitations as well as the effects of RIA technology on the sociotechnical system. The purpose of the HUMANE project is to raise awareness of appropriate human-centred methods and their use in the development and introduction of RIA technology in shipping.

REFERENCES

Cuevas, H. M., Fiore, S. M., Caldwell, B. S., & Strater, L. (2007). Augmenting team cognition in human-automation teams performing in complex operational environments. *Aviation, space, and environmental medicine, 78*(5), B63-B70.

De Stefano, V. (2018). Negotiating the Algorithm: Automation, Artificial Intelligence and Labour Protection. *Artificial Intelligence and Labour Protection (May 16, 2018). Comparative Labor Law & Policy Journal, Forthcoming*.

Fitts, P. M. (1951). Engineering psychology and equipment design.

International Organization for Standardization. (in press). *Ergonomics — Ergonomics of human/system interaction — Part 810: Human/system issues of robotic, intelligent and autonomous systems* (ISO/CD TR 9241-810)

Lutzhoft, M. (2004). *"The technology is great when it works": Maritime Technology and Human Integration on the Ship's Bridge.* Linköping University Electronic Press,

Lutzhoft, M., Hynnekleiv, A., Earthy, J. V., & Petersen, E. S. (in press). Human-centred maritime autonomy - An ethnography of the future. *Journal of Physics: Conference Series*.

Mansson, J. T., Lutzhoft, M., & Brooks, B. (2017). Joint activity in the maritime traffic system: perceptions of ship masters, maritime pilots, tug masters, and vessel traffic service operators. *The Journal of Navigation*, *70*(3), 547-560.

McNeese, N. J., Demir, M., Cooke, N. J., & Myers, C. (2018). Teaming with a synthetic teammate: Insights into human-autonomy teaming. *Human factors*, *60*(2), 262-273.

Shively, R. J., Lachter, J., Brandt, S. L., Matessa, M., Battiste, V., & Johnson, W. W. (2017). *Why human-autonomy teaming?* Paper presented at the

International Conference on Applied Human Factors and Ergonomics.
Sundstrom, E., De Meuse, K. P., & Futrell, D. (1990). Work teams: Applications and effectiveness. *American psychologist*, *45*(2), 120.
Walker, G. H., Stanton, N. A., Salmon, P. M., & Jenkins, D. P. (2008). A review of sociotechnical systems theory: a classic concept for new command and control paradigms. *Theoretical issues in ergonomics science, 9*(6), 479-499.

Use all available means – COLREGs and communication

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Abstract - **Over the past hundred years there have been improvements to regulations at sea, communication systems, and maritime technology. Still, there are points of contention. One example is the issue of ships communicating with each other over the radio to make informal agreements in interacting situations – at times to agree on bending of the rules (the International Regulations for Preventing Collisions at Sea, COLREGs). The aim of this study was to explore to what extent the COLREGs are circumvented in interacting situations today, and in imagined future situations with unmanned ships. Officers of the watch were interviewed and observed during simulated scenarios. The results show that around 50% of the officers use radio communication to clarify interacting situations, and approximately 10% bend the rules. However, all officers would follow the COLREGs unconditionally if the interacting ship were autonomous.**

Keywords
Regulations, COLREGs, navigation, communication.

INTRODUCTION

Communication at sea has advanced from the use of flags, lights and signs when in sight of each other, to Morse code via telegraph, to today's satellite and radio communication. There are requirements for vessels to carry radio equipment, but there are disagreements on whether it is necessary to use radio communication for making informal agreements, i.e. to agree to manage a situation by bending the "rules of the road": the COLREGs (1972). We can only make assumptions and imagine how situations with autonomous and unmanned ships will unfold. The focus of this study was to explore how the officers manage situations today, but also to include an imagined future situation. Are the COLREGs sufficient or are informal agreements used?

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Śniegocki (2009) argues against the use of radio communication in regular navigational situations. He maintains that the COLREGs should be followed unconditionally, and that discussions of possible manoeuvres over VHF can lead to collisions, especially if the manoeuvres are noncompliant with the COLREGs.

We have also seen a substantial development in technology, especially automation and recently autonomy. Some claim that the safety of ships can be dramatically increased by replacing crew with automation and autonomy, while others argue that the efficiency and ship handling are improved by the crew being onboard (Vartdal, Skjong & St.Clair, 2018). This notwithstanding, there is universal agreement that any new solution must be at least as safe, preferably safer, than current ones.

BACKGROUND

In order to explore the use of communication for coordination, we must understand situations where several ships are involved. To frame this study, we use the theory of joint activity, which is an activity where two or more parties cooperate to reach their goal (Klein, Feltovich, Bradshaw and Woods, 2004). In the maritime domain, many parties work together in a joint activity.

If all participants of a joint activity follow the set rules for the situation (in this case, the COLREGs), there exists a basic compact (Klein *et al*., 2004). However, if the basic compact is broken, it should be possible to manage the situation safely if the criteria for a joint activity are followed:

1. All parties take active a part in the situation, and try to understand the other participants' actions.
2. You need to be aware that the interacting party may have another view of the situation than you, and thus it is important to monitor and predict the actions of the interacting party.

3. You have common ground, but you also have the ability to make your own actions predictable if moving in contradiction to the believed common ground.
4. You signal your movements, to make the interacting party aware of your insecurity of the situation and to repair breakdown of the joint activity.

COLREGs

Until the mid-19th century, there were no rules of statutory force (Cockcraft & Lameijer, 2011) and conventions for preventing collisions at sea were local and differing between nations (Werner, 2017). In the mid-19th century steamships arrived on the scene. They did not act as predictably as sailing ships, having the ability to sail in any direction and at "any" speed, regardless of the wind. This led to a need for shared conventions (Werner, 2017).

In 1863 a set of regulations, written by the British Board of Trade in consultation with the French Government, came into operation. These regulations were called articles, and were adopted by more than thirty countries by the end of 1864. This was the beginning of international collision regulations with statutory force, and in 1889 the first International Maritime Conference to consider the matter of collision prevention was held. In 1972 the COLREGs that we know and use today came into use (Cockcroft & Lameijer, 2011), and some of the regulations from the articles are still recognizable.

The COLREGs contain regulations on responsibility, lookout, safe speed, head-on and crossing situations, overtaking, how to act in narrow channels, and actions to avoid collisions, etc. (COLREG, 1972). However, to create regulations for every conceivable situation is almost impossible. *"…the one overriding problem associated with prescriptive rules is the fact that no rule can exhaustively specify the conditions of its use"*(Belcher, 2002, p. 214).

The COLREGs attempt to address this problem with rules such as rule 2, part A, point (b). *"In consenting and complying with these Rules due regard shall be had to all dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which may make a departure from these Rules necessary to avoid immediate danger"* (COLREGs, 1972).

This rule leaves it up to the officer of the watch (OOW) to interpret each situation, to decide when immediate danger may be at hand, and states that it is acceptable to act against the regulations to try to maintain control of a dangerous situation. However, the present study is considering informal agreements in everyday situations, unlikely to be considered dangerous. These agreements are informal in that they are less specific than a formal agreement and they entail a possible bending of the rules – there is a perception that this bending is unimportant and not harmful (Cambridge dictionary online). The aim of an informal agreement is efficiency, effectiveness and avoiding the risk of making a straightforward traffic situation complex and potentially risky.

Bending rules is efficient whereas following rules slows things down. Following rules to the letter has in fact been used as a form of strike; using 'work-to-rule' leads to lower production and efficiency. Another way of describing it is that while demands for productivity tend to reduce thoroughness, demands for safety reduce efficiency (Hollnagel, 2010). Belcher describes how operators see rule bending as elaborations, and as features of their experience and knowledge (Belcher 2002). Presumably, given the above argument, they see it as increasing safety.

According to Corbet and Thomas (1974) many were hoping that VHF as a communication facility would be recognized in the latest collision regulations, COLREGs of 1972. This did not happen. Even though there is no clear regulation on the use of VHF, all ships shall use all available means to determine if risk of collision exists (COLREGs, 1972). This could be interpreted to mean that radio equipment is one of these means, acceptable to determine risks of collision, and to prevent it.

Communication is a much-debated theme in the maritime industry, especially when considering its role in preventing accidents. Froholdt (2015) claims that problems in communication are a key factor that increases the severity of maritime accidents. Froholdt concludes: "…*spoken interaction is used to create a joint understanding of institutional practices and* *information … the elimination of this could hinder the practical realization of the pre-script*" (2015, p. 488).

Belcher (2002) does not directly recommend the use of radio communication, but dismisses the assertion that following the COLREGs unconditionally is the most effective way of managing risks associated with collision avoidance. He discusses a case where two rules suggest or aim to different actions to resolve the same situation. He describes in detail which rules could have been used instead of, or in addition to, these two rules to find a solution that does not lead to danger for any of the involved, *and* complies with the rules. He explains that the solution was found after quite some time, not within minutes, which might have been needed to in a real-life situation; *"… it is clear that the certainty and predictability of collision avoidance may be called into question"* (Belcher, 2002, p. 217).

On the other hand, Stitt concludes: "*If there is a risk of collision, under most circumstances, the action to be taken is clear from the rules. Hence the use of VHF should not normally be necessary*" (2003, p. 76). This view is shared by Śniegocki, who asserts that all vessels should avoid the use of VHF and unconditionally follow the collision regulations (2009). They are both confident that the use of radio communication will work against the COLREGs and make a situation more dangerous than it already is.

As mentioned earlier, we can only imagine how regulations and other factors regarding unmanned autonomous ships will develop. In an ongoing research project, HUMANE, it was found that the participants believed that the way ships interact with other would change. The relationship between human and machine would be different, because the machine would be 'learning' or 'intelligent' – a type of 'robot'. The COLREGs were written with the assumption that there is a human in the loop, making decisions. Humans collaborate with each other and sometimes agree to circumvent the rules – because it is practical or efficient. A robot, on the other hand, is assumed to follow the rules to the letter, and would therefore not be open to negotiation of possible actions. This has an effect on the way a manned ship would interact with an 'unmanned' ship (or a human with a robot); rules would be followed but efficiency sacrificed. Following the rules at all times could even lead to greater traffic complexity; sometimes a small action in contradiction to the rules could simplify a difficult situation. One participant commented: "in a situation with many ships we could end up going in circles" (Lutzhoft, Pikor, Earthy & Petersen, 2019).

METHOD

The methods used were interviews and observations. Interviews provide the opportunity to explore the participants' experience, and observation affords a chance to see what people do, and not only what they say they do (Jacobsen, 2015). The observation was performed within another project, and the authors were invited to include factors of interest to the present study. This was a valuable opportunity to complement the interview method.

Participants

The interview respondents were eleven deck officers; two captains, four chief officers and five 2nd officers. Their seafaring experience spanned 1-31 years, from passenger ships, supply ships, cargo ships and fishing vessels. Five respondents had between 5 and 31 years of experience, and an average experience of 14 years. The remaining six had between one and three years of experience, and an average experience of 1.75 years. The participants in the simulation were 8 deck officers with 3-6 years of experience.

The interviews used a scenario with two ships, one with two conventional ships, and one with a conventional ship and an autonomous ship with an unmanned bridge. The participants were informed that they were on the bridge of a conventional ship and then asked to describe how they would interact with the other ship. Follow up questions focused on their views on initiating and accepting informal agreements, and their stance toward the COLREGs.

The observation was performed in a ship bridge-simulator. The scenario and plan for the simulation for another project was prepared by a group of NTNU students in Ålesund, for another project. The scenarios were conducted in the area around Ålesund, and included two factors of relevance to this study – the crossing situations in the interview scenario, and the possibility that the officers would use radio communication. Notes were taken by hand.

Analysis

Each interview was reviewed separately. The information was then grouped into categories by interpreting statements and using key words such as 'definitely, 'probably and 'usually'. The interviews were analysed as one group, but also divided into two groups, less experience (1-3 years) and more (5-31 years). The observation notes were analysed in several groupings: with and without the TSS, two scenarios, and ship by ship.

RESULTS

The results are presented with the interviews first, then the observations. Lastly, the results are joined in a general summary.

Interviews

The results from the scenario with two conventional ships meeting show that seven out of eleven participants are more positive to passing astern of the interacting ship than ahead (table 1). Examples of reasons given by the participants on why they prefer to pass astern of the other ship is that safety matters and a low CPA is risky. A comment from one of the participants is *"We do not play with these big ships, take the extra minutes if needed."*

Table 1: Conventional ships, passing ahead or astern

Pass astern	Probably pass astern	Open to both solutions	Probably cross ahead	Cross ahead
3	5	1	1	1

One participant is open to both solutions. He says, *"I would have reduced speed, and passed astern. Could of course call the other ship on the radio, but for me the language matters. Could have considered making an agreement if the communication was OK. Or, actually, in real life I would maybe just have passed ahead of the other ship. I am not very sure."*

Two participants are positive to crossing ahead of the interacting ship, but would have made radio contact before acting. One participant adds that the best thing is usually to follow the rules.

Table 2 shows the scenario where the interacting ship was described as an unmanned autonomous ship. It is clear that the participants apply stronger criteria for bending the rules if the interacting ship was unmanned, compared to a conventional ship.

Table 2: Conventional ship, passing ahead or astern of autonomous ship

Definitely pass astern	Would pass astern	Probably pass astern	Best to follow the rules	Would cross ahead
3	5	2	1	0

The participants are less likely to cross ahead of the interacting ship in this scenario. Trust, communication and visual information are words used by the participants when discussing the reasons why. Trust is mentioned both in regards to trusting the technology, and regarding the human ability to monitor several situations at once. Two participants think there will be chaos if one person ashore is to manage several ships and possibly several informal agreements at the same time.

Two participants mention the visual information as a main problem, as they believe that there will be differences between seeing out of a bridge window and monitoring a screen showing the operating area. The participants believe that communication will be impacted, and that it will take longer to get an answer from a land base, than directly from a ship.

There is a range of opinions from the participants on wanting to initiate informal agreements (table 3). One participant would mainly avoid making informal agreements, although he said that in some situations communication could be a solution to problems that are not possible to solve with the rules.

Table 3: Would the participants initiate informal agreements?

Usually if convenient	OK	Depends on the situation	Mainly avoid unless needed	Usually avoid	Avoid
1	3	3	1	2	1

Another participant says that he would avoid making informal agreements, and believes that there is too much talking on the radio in situations that easily could have been solved by using the rules instead. His perception is to follow the rules, and the situations will solve themselves. On the other hand, one participant usually initiates informal agreements if it is convenient, as he considers the value of saving time, fuel, environment and money.

In general, all participants are positive to consenting to informal agreements, and all would at some point agree (table 4). No one is directly negative.

Table 4: Would the participants consent to informal agreements?

Always/usually	Usually	OK	Depends
1	3	3	5

For the five participants saying 'it depends' it was about ensuring that the situation was safe, and that they could get out of the situation if something happened. All five said that they have to make sure that the suggested manoeuvre is safe and convenient for both ships before agreeing.

Three participants consider it acceptable to consent to informal agreements, but add that some factors are of importance, such as communication, CPA, type of trade and type of ship, speed, and advantage for the own ship. Furthermore, two of them said they usually consent to informal agreements, and their doubts seem to be mainly about how beneficial the suggested solution was for their own gain.

The final participant is ambiguous and was coded as both 'usually' and 'always' agree. He reasons, *"If someone first asks, I would often say yes, sometimes even without making a proper evaluation of the situation. It is easy to think that the person initiating the agreement has already considered the dangers of the situation, sometimes I therefore say yes without giving it much thought. But, I know that it is not always the case, therefore I usually say yes, but I try to be better at making my own evaluation first."*

How strongly do they feel about following the COLREGs? Five participants are to some degree positive to following the rules (table 5), and five have the opposite view, with comments like: *"As long as there is an agreement, there is no need for following the rules by word."*

Table 5: How strongly do the participants feel about following the COLREGs?

Follow / it is the bible	Preferably or in general follow	Depends	No problem to bend	Bending rules can benefit
2	3	1	3	2

One of the rule-following participants says that the benefit of the rules is that they cannot be interpreted wrong – and the other praises the COLREGs: *"Very smart to use phrases like safe speed instead of exact speed, with that the rules are just as useful today as it was earlier, when there was for example only sailing ships."*

Does experience matter?

It is not possible to decide on an exact number of years for a distinction between less and more experience. However, when the current data gathered for this project was divided into two groups; 5-31 years and 1-3 years of experience, two distinctions emerged.

Only officers from group 5-31 are positive to crossing forward of the conventional ship and this group also tends to say no to informal agreements more often, if they are insecure of the situation at hand. The other results show no difference; how strong the opinions are about following the rules when interacting with an unmanned autonomous ship, whether they would initiate an agreement and views on following the COLREGs.

Simulation

Eight persons participated in the simulation, two on each bridge (officer and helmsman). Each scenario thus included four manned ships. All participants participated twice; in a scenario without TSS, and in a scenario TSS. Two different traffic scenarios were used. In scenario A, the traffic consisted of the four manned ships, a fishing vessel, a pilot boat, a supply ship, a tourist-boat, a bunker boat and an autonomous ship. Scenario B included the four manned ships, an autonomous ship, two ferries, two supply ships and a containership.

Scenario A without TSS

In this scenario there were no agreements in contradiction to the rules. All participants used the radio for informal or clarifying conversations. There were 14 ship interactions and the VHF was used in eight.

Scenario A with TSS

One participant followed the COLREGs, and did not use the radio. Three participants made clarifying conversations, and one of these three also wished to perform an action in contradiction to the rules, which was met with an agreement of the interacting vessel who was also one of the participants. There were 11 ship interactions and the VHF was used in eight.

Scenario B with TSS
Three participants did not use the radio in this scenario. One participant used the radio for clarification of another ship's plan. In eight interactions, the VHF was used once.

Scenario B without TSS
Two participants in this scenario did not use the radio. One participant used the radio to clarify situations *and* initiated an informal agreement, and one participant initiated an informal agreement. These two participants initiated agreements in contradiction to COLREGs, and went through with it. Out of ten interactions, the VHF was used in three.

Summary
Even though it is strictly not possible to generalize, it is interesting to note that in more than 50% of the observed situations, the officers needed clarification in addition to using the rules. More than 10% acted in contradiction to the rules, while just under 40% managed the situations by using the COLREGs.

DISCUSSION

In the interviews, even the two participants who were the most negative to using communication in addition to the COLREGs commented that they *would* use communication, but only to clarify situations. Thus, all the interviewees are to some degree positive to this kind of communication. In the observation, nine out of sixteen participants participated in clarifying conversations. With all interviewees open to such conversations, and with more than 50% of the observed participants performing such conversations, it seems that the COLREGs are not enough to make the participants feel safe in close encounters. They need something more.

This need becomes even clearer when looking at how many participants actually "bend" or act in contradiction to the rules. Here, five out of eleven of the interviewees are positive to making agreements in contradiction to the rules. Four out of eleven participants were positive to initiating to such agreements, while all participants agree they would bend the rules at times. One of the interviewees said that, despite his preference for following the rules, communication can at times be a solution to problems that the rules cannot solve. The observations support these results to some extent, as more than 10% of the observed participants made agreements to bend the rules.

The observation was performed in scenarios with ten ships or less, in addition to three or four leisure craft. It is striking that, even in a scenario this limited, so many participants feel the need for something to support their decisions in addition to the rules stated in COLREGs. It is not difficult to believe that in a busier seaway, the need would be even greater.

However, there are participants who really value the COLREGs, which must be considered as well. During the interviews, five out of eleven participants were more negative than positive to bending the rules. One is neutral, and says that the context of the situation matters. Two speak very highly of the COLREGs, they describe it as smart; one of them calls COLREG the bible, while the other asserts that the rules are very clear, and hard to interpret incorrectly. Furthermore, in the observation about 40% manage all situations by only using the COLREGs.

There is support for the unconditional use of COLREG, and a belief that communication actually can work against its intention, as Stitt (2003) and Śniegocki (2009) claim. Even so, Śniegocki (2009) admits that VHF can be a good working tool, but not a tool to abuse in collision situations. Froholdt (2015) is of the opinion that communication can help to create a joint understanding of situations. The COLREGS may not suffice to predict the outcome of all situations. If that is the case, there is a need to repair the breakdown. It is possible that radio communication is a valuable tool to retain common ground, and thus repair breakdowns, to manage interacting situations without danger.

Will unmanned ships change ship interactions?

In the situation presented during the interviews, no interviewees were positive to crossing ahead of an unmanned autonomous ship, compared to the situation with two conventional ships, where two participants were positive to cross ahead of the interacting ship, together with two neutral participants who were open to both solutions. So why is this?

Common ground is an important part of joint activity, and some of the key aspects for common ground are knowledge, beliefs and assumptions. Furthermore, it is necessary to monitor and repair breakdowns, and continually inspect and adjust common ground. When the other ship was an unmanned autonomous ship, the participants are unsure whether a person ashore would respond to their signals and therefore are not certain that it is a good idea to leave the basic compact. They do not know what would happen to the monitoring of the situation and are concerned that that the operators in the land-station would not see the situation exactly as they do, due to a difference in available visual information.

The participants also doubt that it would be possible for one person to monitor and manage one specific situation with full attention, if the job was to monitor several ships. They believe that if communication were needed, it would be more time consuming than today, since they would not be able to speak with the ship directly. Therefore, they are also concerned that *if* they were to contradict the rules, due to whatever reason, it might not be possible to repair a potential breakdown of the situation and the basic compact.

Compared to the situation with two conventional ships, it appears that officers meeting an autonomous ship would follow the COLREGs unconditionally. It is possible that the common ground and the basic compact are of more importance than in a situation where the other ship is conventional. The officers now believe that following the rules is the better choice – to keep the basic compact, instead of having to manage the situation by addressing the subsequent steps of joint activity; to monitor the situation, or to repair potential breakdowns. One can argue that this is due to the absence of direct contact with humans in the unmanned ship situation. The autonomous unmanned ship is assumed to not have a human's ability to adapt to the situation, and to have pre-set or pre-programmed functions.

Humans sometimes agree to contradict the rules, because it is more effective or for some reason more convenient. Robots, or in our case unmanned autonomous ships, are assumed to follow the rules, and will therefore not negotiate, or make other actions in contradiction to the rules. Therefore, it is possible that an unmanned autonomous ship is more likely to follow the basic compact. However, what will happen if everyone follows the rules unconditionally? Will it influence the traffic flow at sea? Will it be safer than sometimes acting in contradiction to the rules?

CONCLUSION

The aim of this project was to get a better understanding of officers' views about interacting situations and the use of COLREGs.

- Five out of eleven interviewees were positive to making agreements in contradiction to the rules. Four out of eleven were positive to initiate to such agreements, while all agree that at times they would bend the rules.
- All interviewees appear to be open to take part in clarifying or informal conversations, even though not necessarily to contradict the rules.
- No interviewees were positive to crossing ahead of an unmanned autonomous ship.
- Around 40% of the observation participants manage situations by using the COLREGs.
- 10% of the participants in the observation acted in contradiction to the COLREGs.
- More than 50% of the participants from the observation need, at times, something in addition to the rules, to clarify situations.

The officers seem to rely more on the unmanned ship following the rules and keeping the basic compact. For the officers, this is more predictable than the ability of an autonomous ship to repair breakdowns that might arise if acting in contradiction to the COLREGs. This is also supported by results from the HUMANE project; an autonomous ship is more likely to follow the basic compact than a conventional ship (Lutzhoft *et al*., 2019).

Based on this, it is possible to conclude that the OOW´s are not fully committed to the use of the COLREGs. Although some participants disapprove of bending the rules, all participants are to some extent prepared to act in contradiction to the rules. It appears that in interactions between conventional ships, officers consider radio communication to be a tool to retain common ground when needed. It is also a means to repair breakdowns in order to manage interacting situations in a safe manner.

Officers believe that they will not be able to rely on unmanned autonomous ships to repair breakdowns of the common ground, and that the basic compact is more likely to be kept by an unmanned autonomous ship. Officers therefore believe they will be more consistent in following the COLREGs when in an interacting situation with such ships. The final result for maritime traffic may be more thoroughness but less efficiency.

REFERENCES

Belcher, P. (2002). A sociological interpretation of the COLREGS. The Journal of Navigation, 55, 213-224. doi: 10.1017/S0373463302001686

Cambridge Dictionary (online) https://dictionary.cambridge.org

Cockcroft, A. N., & Lameijer, J. N. F. (2011). A guide to the Collision Avoidance Rules 7th edition. Amsterdam: Butterworth-Heinemann, Elsevier.

COLREGs (1972). Convention on the international regulations for preventing collisions at sea, 1972. Retrieved from IMO-Vega.

Corbet, A. G. & Thomas D. H. (1974). The Maritime use of V.H.F. Radio-telephony-Present and Future. The Journal of Navigation, 27(2), 158-162. doi: 10.1017/S0373463300025881

ETHW. (2015). The sea and early electrical technology. Retrieved from https://ethw.org/The_Sea_and_Early_Electrical_Technology

Froholdt, L. L. (2015). 'I see you on my radar': displays of the confirmatory form in maritime technologically mediated interaction. The Sociological Review. Retrieved from [https://onlinelibrary.wiley.com/doi/full/10.1111/1467-954X.12333]

Hollnagel, E. (2010) The ETTO Principle: Efficiency-Thoroughness Trade-Off–Why Things That Go Right Sometimes Go Wrong. Risk Analysis. 30: 153–159.

Jacobsen, D. I. (2015). Hvordan gjennomføre undersøkelser?: Innføring i Samfunnsvitenskapelig metode. Oslo: CAPPELEN DAMM AS

Klein, G., Feltovich, P. J., Bradshaw, J. M., & Woods, D. D. (2004). Common Ground and Coordination in Joint Activity.

Lutzhoft, M., Pikor, A., Earthy, J.V., Petersen, E.S. (2019)

Śniegocki, H. (2009). VHF portable radio as a tool for preventing collision at sea.

Stitt, I. P. A. (2003). The Use of VHF in Collision Avoidance at Sea. The Journal of Navigation, 67-78. doi:10.1017/S0373463302002035

Vartdal, B. J., Skjong, R., St.Clair A.L. (2018). Remote-controlled and autonomous ships. DNV GL - Maritime

Werner, J. (2017). The History of the Rule of the Road – Sailing Vessel History. Retrieved from https://www.allatsea.net/the-history-of-the-rule-of-the-road/

OpenBridge: Designing for Consistency Across User Interfaces in Multi-Vendor Ship Bridges

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Abstract - **Navigating crew on ship bridges are often using a variety of systems that lack consistent user interface design from one system to another. Consistency across systems is an essential aspect for reducing human error and increasing user ability in workplaces where users interact with a variety of physical and digital systems. Currently, a lack of regulations and design guidelines do not offer a clear path towards user interface consistency on ships bridges. Thus, there is a need to develop user interface guidelines that may help realize consistent design for all maritime systems across different maritime vendors and equipment. We present one such system by reporting recent updates from an industry-driven project seeking to regulate the relationships between ship bridge (i) integrators and (ii) system vendors through a design system. We argue that our proposed design system may help realize design consistency across multi-vendor bridges and contribute to an improvement of the quality of ship bridges, the work environment for seafarers and overall ship safety.**

Keywords
consistency, user interface, design system, multi-vendor ship bridge, design guidelines, OpenBridge

INTRODUCTION

It is a common problem in current ship bridges that they include a large number of systems, supplied from a variety of manufacturers, with few common design traits (Nordby & Morrison, 2016; Oltedal & Lützhöft, 2018). Consistency issues are likely to arise for any multi-vendor ship bridge (MBS), i.e., a bridge with multiple systems delivered by two or more independent contractors. This can create problems for modern ship bridges once put into operation. In particular, this issue becomes increasingly serious in advanced and specialized ships, which often include a large number of systems for many different vendors. We refer to "system vendors" and "system integrators" as the suppliers of respectively individual systems, and the integration of individual systems (Nordby, Mallam, & Lützhöft, 2019). Both vendors and integrators must address issues of design consistency because of its effect on end-users and the safety of operations (Nielsen, 2014). Mišković, Bielić and Čulin (2018) found that a significant number of end-users reported having been confused by the information provided in bridge systems, linking the finding to too many different types of equipment on the bridge.

Research in human-computer interaction show that consistency in user interface design may help users in transferring skill in using one system to another. It is also connected to usability, efficiency and reduced error rate (Nielsen, 2014). Design consistency can be defined across many components of a user interface. For instance, the graphic design of the user interface, such as spatial organization of components, colors, symbols and typography. It also relates to aspects of interaction design, such as structure of content, user interface patterns and interaction mechanisms. In a maritime setting, we can also define consistency across a single system (e.g. Electronic Chart Display and Information System - ECDIS) or multiple systems on a single ship. This is often the case for integrated bridge systems (IBS) where one system integrator has assembled systems from different vendors, such as: Radar, GPS, Conning, Radio and Dynamic Positioning (DP). Consistency is also related to using several IBS in one ship, or even across multiple ships.

So far, maritime authorities have not managed to solve this problem through regulation and guidelines. In a review of current design regulations and guidelines for the maritime sector, Mallam and Nordby (2018) found that none of the documents would lead to consistent user interfaces across all ship bridge systems. There have been recent efforts such as the S-mode initiative that aims to introduce consistency across navigation equipment (Lee, Lemon, & Lützhöft, 2015; IMO, 2019). However, in its current state we will argue it is unlikely that this initiative will offer comprehensive guidance that will lead to significant user interface consistency for MBS installations.

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Currently there is a challenge to achieve any level of consistency since ships bridges are made of an assembly of applications from many vendors with little or no coordinated design. In order to bridge this gap, there is a need for new approaches to workplace design and ship development oriented towards a higher level of consistent design across all systems on a ships bridge.

AN OPEN PLATFORM FOR CONSISTENT USER INTERFACES

This article reports ongoing work in the OpenBridge project (OICL, 2018). The project was initiated in 2017 with a purpose to achieve cross-vendor integration and consistent user interfaces for all maritime equipment in a ship´s bridge. We consider each user interface as an access point where the user can interact with the bridge systems, and argue that there is a need for design guidelines that enable users to work efficiently and safely with any interface across all the bridge systems.

The project is driven using an open innovation approach (Chesbrough & Appleyard, 2007) with significant industry collaboration with 27 partners from industry, government and academia. Industry partners include ship owners, system vendors, bridge system integrators, ship yards. Government include local and international regulation agencies. Academic partners cover disciplines such as graphic, interaction and industrial design, human factors and ergonomics, and human-computer interaction.

The maritime industry is under high economic pressure and a change in the industry is challenging to achieve if it raises any cost. In this context, OpenBridge is built together with industrial partners, with a focus on the economic feasibility and practical implementation of the proposed concepts and solutions. One strategy to achieve this goal is to integrate existing tools and processes that are well developed in other industries. For instance, the web and mobile-oriented industries (web industries) and their expertise and experience in developing user-centered digital technologies (Nordby, Mallam & Lützhöft., 2019). We refer to developers of operating systems (such as Android, Windows and iOS) who have produced and distributed comprehensive design guidelines connected to software development resources that make it convenient for application developers to follow their design philosophy (Apple, 2018; Google, 2018; Microsoft, 2018). We derived much of work from Google material design (Google, 2018) because of the availability of a comprehensive support material and its familiarity as one of the best-known design systems.

The core deliveries of OpenBridge are a voluntary design guideline and a set of implementation tools that together make up a "design system" that explicitly lays out how to design central parts of maritime digital user interfaces. The project follows an incremental and iterative approach, starting with guidelines for basic components, such as buttons and typography, before working with more overarching concepts such as application layout and interaction patterns.

OpenBridge is a design system, by which we mean a modular user interface design methodology built on web technology that merges traditional design guidelines with development tools. A design system is an adaptive system that supports a portfolio of applications, and is in continuous development to respond to new needs (Curtis, 2010; Nathan, 2016).

OpenBridge is based upon a user interface architecture in three levels (Nordby, Mallam & Lützhöft, 2019). As shown in Figure 1, the first level deals with the physical components making up a workplace – we refer to this level as "workplace hardware". The second level looks at the integration system that defines how applications may be integrated into a workplace. The third level is concerned with applications that represent the various ship bridge systems. The user interface architecture makes a distinction between the development of applications (level 2), workplace hardware (level 1) and integration system (level 3). This distinction enables development of design guidelines for each level, that are also consistent from one level to another. The goal is to enable applications developers to design applications that will behave predictably on all OpenBridge compliant ship bridges.

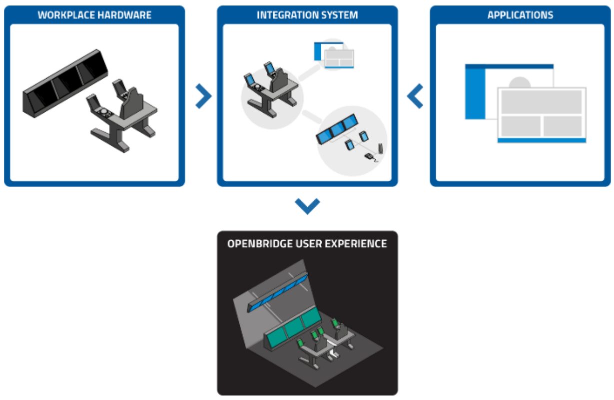

Figure 1 OpenBridge User Interface Architecture.

The development of the OpenBridge design guidelines has been based upon three design principles commonly in use in the web industries to deal with consistency (Nordby, Frydenberg, & Fauske, 2018). The first principle is responsive design, which allows user interfaces to scale to screens of different sizes. The second principle is style theming, which allows to alter the visual appearance of the user interface through simple scripting. Finally, we used standard user interface components, with a focus on fundamental building blocks such as buttons, toggles, etc., that make up a user interface.

OPENBRIDGE DESIGN GUIDELINE

In the OpenBridge design system, the different applications run by the different systems are mediated through work stations. By application, we refer to software programs such as DP, ECDIS and wiper control systems. Examples of maritime applications we have initially focused our work on include: compass systems, echo sounders, deck light systems, conning displays, electronic chart systems, alert systems and interfaces for propulsion systems. Each workstation consists of workplace hardware, and an integration system that organizes software resources so that applications can be shared across different pieces of workplace hardware. This way the definition of workplace differs from current maritime industry practices in that it defines applications and integration platforms as independent from each other, but with standardized connection. With this approach based on standardizing individual systems, and the connections between systems, it is possible to design applications that can work across all integration systems that adhere to the OpenBridge guidelines.

Application Design

All systems are represented as applications that can be mediated through graphical user interfaces (GUI). These GUI's are, to a large degree, made up of simple user interface components. OpenBridge offers a series of standardized libraries of components that can be used to assemble a GUI: simple component such as buttons, nested components (e.g. menus), and maritime components (e.g. thruster visualization). Figure 2 shows a collection of simple OpenBridge user interface components. By offering reusable GUI components we secure consistency on component level across OpenBridge applications.

In addition to the component libraries, the OpenBridge system offers a structure template for building basic user interfaces. This structure is applied to all OpenBridge components and focuses on generic user interface functions most applications need. It describes where to place common functions such as application navigation and dimming. The application structure secures design consistency related to functions that are generic for all OpenBridge applications.

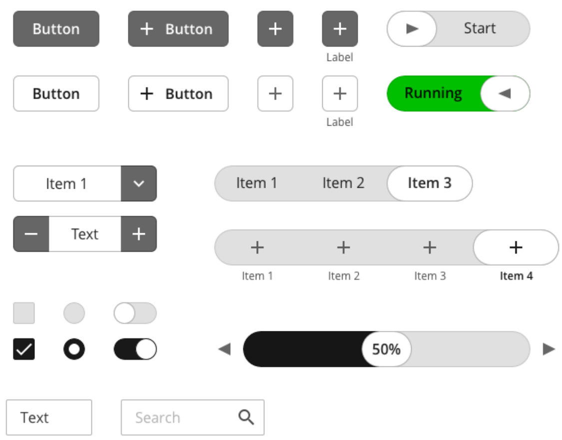

Figure 2 OpenBridge User Interface Architecture.

The OpenBridge concept has developed from its initial formulation, documented in Nordby, Frydenberg & Fauske, 2018. The following section describes these changes and evolving development of OpenBridge. This includes a revised version of the application structure and its main components. The new elements that are connected to the integration system are then described. Finally, we present an early version of an integration system application for screen management.

Application structure

All OpenBridge applications are made up of a small selection of nested user interface components that together make up a generic applications structure. These components are collected in the top bar, which is the main component in all applications and can scale to any screen size (Figure 3). The left side of the top bar contains the navigation menu button and an area for application name and status.

On the right side, we have placed buttons to control three main features present in all applications: the alert menu button, the dimming and palette menu button, and the application selection button. In addition to these mandatory buttons, we have allowed some optional features in the top bar, such as a display of time and day, as well as buttons linking directly to essential applications.

The top bar is designed according to principles commonly found in mobile and web applications. In the following sections, we will present the various components that can be accessed through the top bar.

Figure 3 OpenBridge User Interface Architecture.

Main navigation menu

Many of the applications we have investigated in our research make use of a hierarchical navigation menu. We offer access to a standard navigation menu through the navigation menu button on left side of the top bar. The navigation menu button links to a large menu occupying the left side of the screen (Figure 3). It includes an optional search component and a hierarchical access to pages within an application. It is possible to expand or collapse nested sections in the menu. When a page has been selected, the name of the page will be shown after application name in the top bar.

In our previous studies of existing applications, we found large variations in design of navigation across applications (Nordby, Mallam & Lützhöft, 2019). We argue that by standardizing the main navigation in an application it will be easier for users to learn and to predict where to find functions in all OpenBridge applications.

We have positioned two links in the bottom of the menu: a company link button, and a settings page that controls a comprehensive list of settings (see section: "Settings page"). Existing maritime user interfaces have often company logos embedded in the front of applications. In order to avoid clutter, we have instead allocated a standard area in the navigation menu for logo representation. The logo functions as a button that may show a small alert for updates. When pressed it open a large section that vendors delivering the application can design freely. In this way, the logo has a meaning in the system as it offers access to company related content.

Alert section

The alert menu button has a unique role in the interface. If an alert is triggered the button expands to include an alert icon, descriptive text, buttons for "mute alert" and "acknowledge alert", and a time stamp (Figure 4). From there it is possible to interact with the alert directly in the top bar. By pressing the alert button, a fly-out menu shows an overview over a list of recent alerts. On the bottom of the list, we have placed a link to the alert center, which opens an application that governs all alerts.

By integrating a common alert section in all applications, we envision that alerts are a common feature that applications need to share.

Application selection menu

The button opens up a menu that offers shortcuts to essential applications in the system (Figure 5). This facilitates fast selection of critical or frequently used applications. The design is based on the application menu commonly found in, for example Google and Android products. Clicking on any of the icons will open the connected application. We do not envision that all applications should be reached through the icons. Instead we have added a link to a full application center on the lower part of the menu.

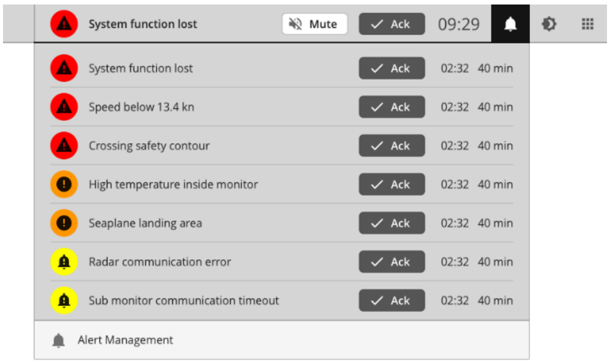

Figure 4 Alert section: expanded state.

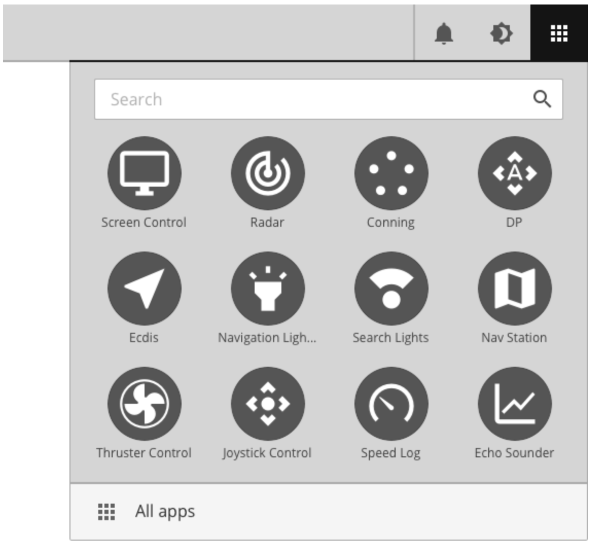

Figure 5 Application selection menu.

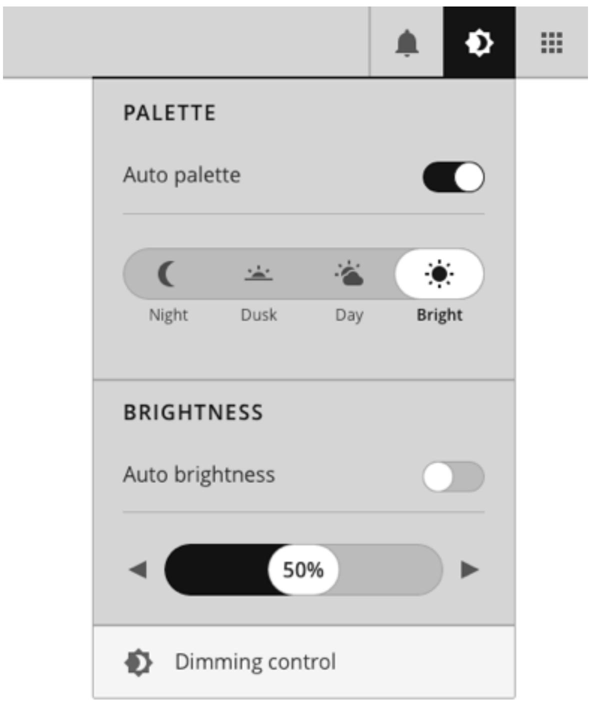

Figure 6 Dimming and palette menu.

Dimming and palette menu

The dimming and palette icon offer access to control of screen dimming and palette selection for the selected screen (Figure 6). It also includes a link to an application allowing detailed dimming setup for the entire workplace.

Settings page

Many of the applications we have analyzed in OpenBridge have extensive setting pages. In order to make the navigation in these settings manageable for the users, we propose a standard setting page with a hierarchical structure. The setting menu opens from the navigation menu and can be discarded using the close button (Figure 7).

Together, the structure and components described above offer a foundation for application design that enables cross applications consistency, and helps form a common design on generic application functions. We argue it is likely such a common structure will make the user interfaces more predictable and easier to learn.

Integration system

In the previous section we described the basic structure of OpenBridge applications. In order for these applications to work together, there is a need for guidelines for how to design the integration system. Design guidelines for the integration system governs how to design user interface elements that are shared amongst different applications as well as applications that govern the workstation itself.

Examples of shared user interfaces elements include dimming and applications sharing components shown in the previous section. We see these as representations of the integration system that can be reached through all applications.

In addition to these examples of integrated applications, we are adding other applications that manage the integration system itself. On a basic level, there is a need for the integration system user interfaces to be compatible with the design of application user interfaces. For instance, it is necessary to make sure application selection can be reached in the same way on all applications. However, since there is also a benefit for users to have predictable ways of manage a workplace, we are experimenting with reference designs for workstation management.

An example of this is the screen management application. This application allows the user to control the content and management of all screens in a workplace (Figure 8). The system includes local dimming for all screens, task-based control of workstation´s setup, and the ability to open up

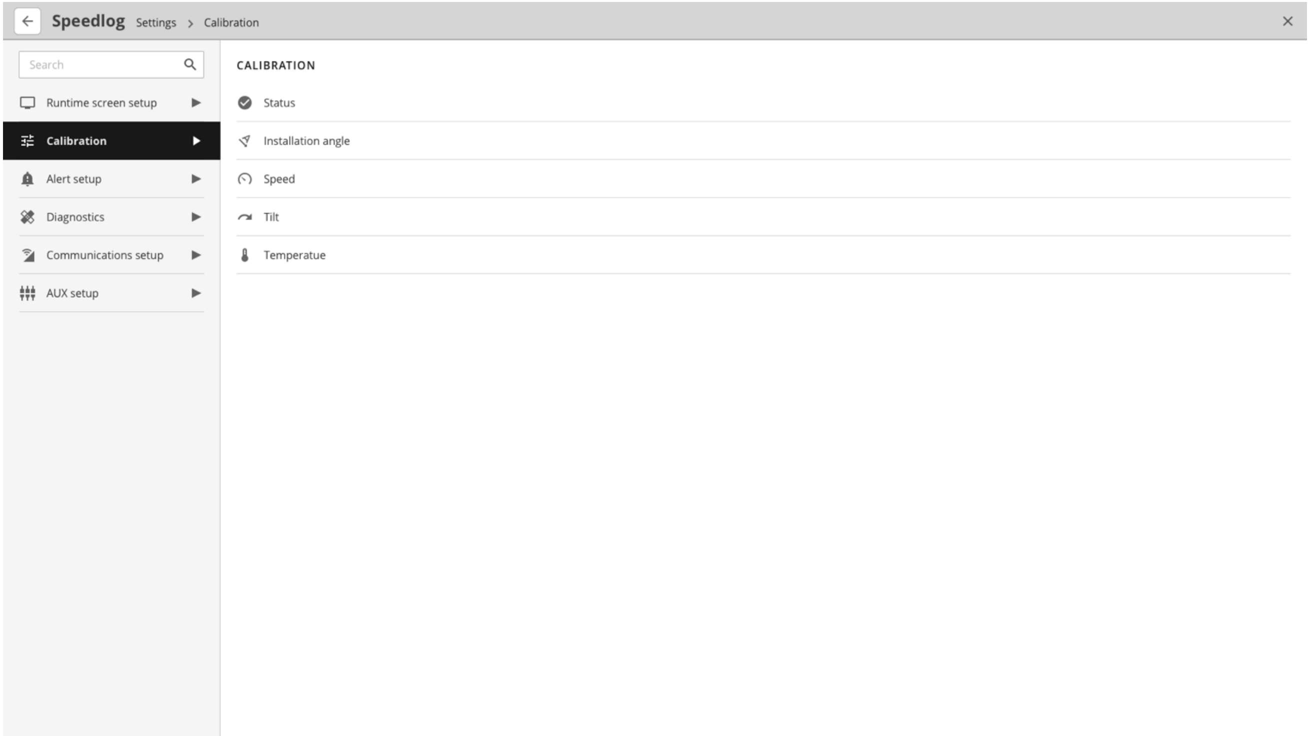

Figure 7 Setting page of Speedlog Application.

multiple applications on the same screen. The applications are designed using OpenBridge components and structure, but are still a part of the integration system that make it possible for applications to be accessed on the workstation.

We are currently evaluating what other management applications are necessary in the integration system. It is likely that we will develop applications for the control of the interior environment (for example temperature and ventilation) and collections of functions for exterior control, such as access to wiper systems and lighting. Each of these systems, such as window wipers, will still be individual OpenBridge applications. However, they might deliver smaller user interface elements that can be integrated into groups of other related functions, so as to make it possible to operate them more efficiently.

Multimodal technologies

Maritime workstations need to support diverse and challenging work situations. Multimodal technologies may therefore be a necessary addition to maritime workplaces (Nordby & Lurås, 2015). The OpenBridge user interface architecture is built to support the inclusion of multimodal technologies that work together with the graphical user interface (Nordby & Morrison, 2016). For example, physical interaction devices such as levers and buttons and for more advanced systems, technologies such as gaze tracking, voice and gesture control.

A specific example of multimodal technology developed with OpenBridge is augmented reality user interfaces. This technology enables to superimpose digital information onto the real world, using screens and head-mounted displays. We are currently designing an OpenBridge compliant design guideline for augmented reality on ships through the SEDNA research project (Frydenberg, Nordby, & Eikenes, 2018). This work focuses on making it possible for applications designed for screen to be extended into AR space, highlighting the need for supporting multimodal technologies in the workplace. User interface guidelines for these new formats are designed together with the integration platform and application guidelines. In doing so it is possible to extend design consistency to emerging technologies.

The project expects to engage in tangible user interfaces within the next year. It is natural to extend the user interface component library for digital user interfaces into physical interaction as well. This will include physical interaction mechanisms such as buttons and levers. We have observed a significant variation in how nested button interfaces are designed. We plan to extend design requirements for such interfaces in the OpenBridge design guideline. This will also include design guideline for typography for physical labels and other graphics that are consistent in style and readability with the screen based OpenBridge interfaces.

By extending OpenBridge design guidelines beyond screen and toward additional existing and relevant future ones, we strive to achieve multimodal design consistency.

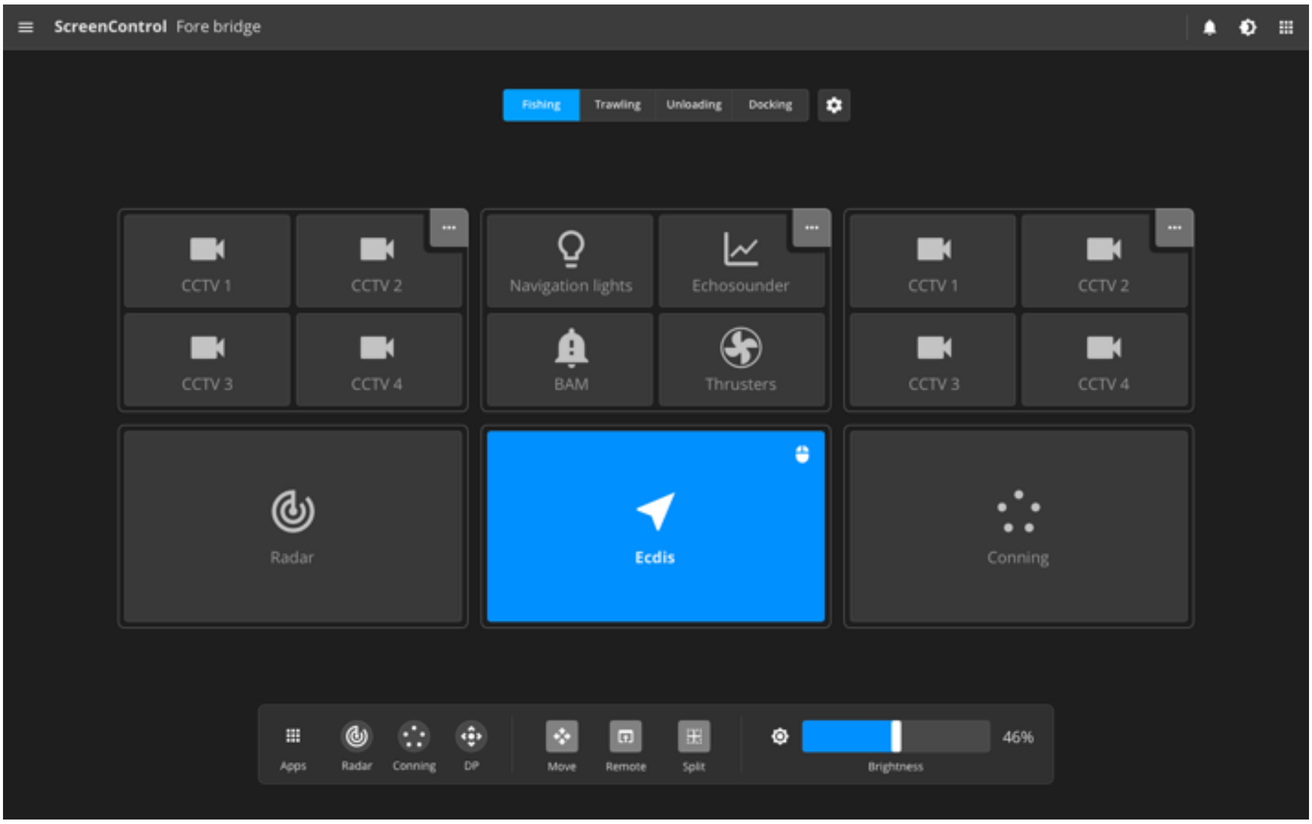

Figure 8 Example of application integration.

DISCUSSION

User benefits

OpenBridge offer two main kinds of benefits for end users. First, we argue the OpenBridge workplaces will be able to draw on the benefits related to consistent design. This include ease of learning, more efficient use and reduced human error. In addition, we expect individual applications built according to OpenBridge will achieve individual benefits. This is because the OpenBridge components and structure are being iteratively developed and tested by users in ways that are not always the case in maritime development. Since the project focus on components there is a rigorous process of improving them that will benefit any applications that have them integrated into its design.

We argue these potential effects of OpenBridge will lead to better maritime workplaces and overall higher ship safety.

Industry adoption

Our industry partners report on the importance of delivering a system that can be implemented without increasing significantly development cost. We have identified increased costs as an inhibiting factor in realizing OpenBridge.

To meet this challenge the project follows an open innovation strategy for transferring OpenBridge to industry. We lower the bar of using OpenBridge by making key contributions, such as the design guideline, a free online resource. In addition to the open strategy, the system brings a number of cost-saving possibilities.

Since OpenBridge clearly defines generic functions in a maritime user interface and offer reusable components, it is leveraging some of the benefits in using reusable resources that are associated with design systems that are in use in the web industries. There is a possibility to directly reuse code and by that securing high quality and lower cost in development. Also, it will require less resources in forming generic functionality such as dimming interface and application launcher since they are already specified.

Besides potential economic benefit, we also strive to make the system easy to find and apply in industry development processes. This is being achieved through making an online resource that includes detailed design specification and best practice design exemplars showing approvable OpenBridge designs. The project has a high emphasis on addressing the usability of the design guideline itself by involving industry partners in the development of online resources. We argue this is a very important part of advancing the use of the design guideline since an easy to use design guideline itself will make it more cost effective for the industry to implement OpenBridge in their systems.

Regulation

It was earlier discussed in the project consortium whether strict maritime regulation would limit the potential of realizing OpenBridge. After an analysis of existing regulation, we found that although regulation limits some of the ways we might implement user interface technologies; there are surprisingly little regulation that limit our user interface guidelines (Mallam & Nordby, 2018). If anything, our guideline is arguably stricter than existing guidelines.

Also, we have found that existing regulation do not achieve design consistency in the maritime industry, but rather provide high level design guidance (Mallam & Nordby, 2018). OpenBridge solves this by delivering a prescriptive design guideline that complies with existing regulation. The goal is that any interface designed according to OpenBridge guidelines will automatically follow maritime regulation.

Innovation

A challenge in offering prescriptive rules is that they may limit innovation since they are locking down key functions of a user interface. However, OpenBridge does not replace the need for user interface competence in maritime application development. The system offers digital components for generic functionality and components that are shared among most applications. The main functions of maritime applications still need to be designed and rigorously user tested in order to make efficient user interfaces. The sole purpose of OpenBridge is to establish the basic building blocks and the foundational structure of an application are optimal and then applied consistently across multiple applications.

On the other hand, it will be easier for new actors to develop applications that are compatible with maritime workplaces. This can potentially lower the threshold for delivering new innovative functionality to ships bridges. Further, a common framework for user interfaces make it possible to introduce new multimodal technologies as a common resource for all applications in a ships bridge. This will make it easier better adapt workplaces to special operational needs.

Finally, innovation itself poses a challenge for OpenBridge. As technology and operations evolve there will be a challenge in making sure OpenBridge are up to date. In order to maintain relevance, we are applying a process of iterative development of OpenBridge where the system is in continuous evolutionary development. Futhermore, as ships are large investments, they are generally intended to be in operation for several decades. Thus, onboard equipment and systems go through several updates and retrofits throughout its lifecycle. Such process raises questions on how to manage different version of OpenBridge across different generations of equipment on a ships bridge. The project will address this problem together with industry partners and regulatory authorities through the ongoing project.

CONCLUSIONS

We have presented work carried out in the OpenBridge project that seeks to improve design of user interface on ship bridges. The first deliveries of the project focus on prescriptive design guidelines related to application design. The next stage will widen the focus to physical hardware, multimodal technologies and the integration system.

We argue that OpenBridge have the potential to realize consistent design across all maritime user interfaces on user interface components, applications structure, workplace management and multimodal interaction. By doing this we secure consistency across features that can be shared across the many maritime system that are part of a ships bridge. This can potentially lead to better and safer workplaces at sea while simultaneously reducing cost and heightening innovation across the maritime industry.

ACKNOWLEDGEMENTS

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REFERENCES

Apple. (2018). iOS Design Themes. Retrieved from https://developer.apple.com/design/human-interface-guidelines/ios/overview/themes/

Chesbrough, H. W., & Appleyard, M. M. (2007). Open innovation and strategy. *California management review, 50*(1), 57-76.

Curtis, N. (2010). *Modular web design: creating reusable components for user experience design and documentation*: New Riders.

Frydenberg, S., Nordby, K., & Eikenes, J. (2018). Exploring designs of augmented reality systems for ship bridges in Arctic waters. *Human Factors, 26*, 27.

Google. (2018). Material design. Retrieved from https://material.io/guidelines/

IMO. (2019). Guidelines for the standardization of user interface design for navigation equipment. MSC.1/Circ.1609 14 June 2019.

OICL. (2018). OpenBridge website. Retrieved from http://www.openbridge.no

Lee, S., Lemon, N., & Lutzhoft, M. (2015). Harmonizing guidance for future ship navigation systems.

Mallam, S. C., & Nordby, K. (2018). *Assessment of Current Maritime Bridge Design Regulations and Guidance*. Report Prepared for the Open Bridge Project: The Oslo School of Architecture and Design.

Microsoft. (2018). Design basics for UWP apps. Retrieved from https://docs.microsoft.com/en-us/windows/uwp/design/basics/

Mišković, D., Bielić, T., & Čulin, J. (2018). Impact of Technology on Safety as Viewed by Ship Operators. *Transactions on maritime science, 7*(01), 51-58.

Nathan, C. (2016). A Design System isn't a Project. It's a Product, Serving Products. Retrieved from https://medium.com/eightshapes-llc/a-design-system-isn-t-a-project-it-s-a-product-serving-products-74dcfffef935

Nielsen, J. (2014). *Coordinating user interfaces for consistency*: Elsevier.

Nordby, K., Frydenberg, S., & Fauske, J. (2018, 26th - 27th September). *Demonstrating a maritime design system for realising consistent design of multivendor ship's bridges.* Paper presented at the Human Factors, London, UK.

Nordby, K., & Lurås, S. (2015). *Multimodal interaction for marine workplaces used as strategy to limit effect of situational impairment in demanding maritime operations*. Paper presented at the International Conference on Marine Design, London.

Nordby, K., Mallam, S. C. & Lützhöft, M. (2019). Open user interface architecture for digital multivendor ship bridge systems. WMU Journal of Maritime Affairs, 18(2), 297-318. DOI: 10.1007/s13437-019-00168-w.

Nordby, K., & Morrison, A. D. (2016). Designing calm technology and peripheral interaction for offshore service vessels. *Personal and Ubiquitous Computing, 20*(4), 601-613.

Oltedal, H. A., & Lützhöft, M. (2018). Design for safety. In *Managing Maritime Safety* (pp. 116-150): Routledge.

Foresight Future Skills in Digitalisation Era: The Role of Participatory Design in Simulation-based Maritime Education

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Abstract – **A few studies in the maritime domain utilize participatory design (PD) in ship design workshops, however, none of them addresses a full picture of how PD can make changes in simulation-based maritime education. In this reflection paper, we answer how PD can help to foresight future skills in the maritime domain, especially on how to use simulators to support increasing competence of seafarers and in turn to redesign simulators to support maritime education. In this paper, we aim to uplift the experimental skills of current debate from normal science to a socially embedded marine technology, addressing collaborative and innovative research activities, to enable all participants (seafarers, trainers, technicians, authorities etc.) to share their experiences so a joint recognition of needed future skills can be reached. Along with the exchange of experiences, we assert that the supported simulations and simulator techniques could be designed to achieve sustainable growth for all participants as well as the upcoming digitalisation era in the maritime domain.**

Keywords
Participatory design, simulation-based maritime education, future competence.

INTRODUCTION

A Norwegian television program, Lykkeland[1], reveals the interesting history of how Norway became a world-leading maritime nation. From the program, viewers learn how the Gulf Stream brings Norway immense fishing opportunities but it also indirectly shapes the country's socioeconomic structure from its maritime technologies and worldwide operations to its vivid maritime history and culture. As a result of improvements in information technology and infrastructure, marine technologies and operations have dramatically evolved from traditional automatic, mechanical, mechatronic-based technologies to digitalisation[2] - based intelligence, human-centred, and information and communication technologies (ICT) supported smart operations. Such changes subvert the traditional evaluation of the competence of individual labours. As such, it is worthy to question whether Norway is ready for the pluralization of the high-tech revolution and is able to lead the future maritime domain. Can Norway still produce high competence individual labours and maritime organizations that will lead the maritime world in adopting those high-tech solutions?

To answer these questions, we should review the Norwegian maritime education and training system in current digitalisation process of marine technologies and maritime organisations. Currently, Norwegian maritime education consists of three main venues: vocational education (fagskole), technical colleges (høgskolen), and comprehensive universities. Along with several training companies across the country, these three educational systems contribute to disequilibrium. For example, vocational education and technical colleges primarily focus on utilizing simulators to train seafarers from the novice to the proficient level. After that, course certificates are awarded to students who later achieve some experience at sea then get certificates from the maritime authority of Norway. Certificates are primarily only paper that describes a position in the maritime industries. Alternatively training companies also offer training programs to seafarers and offer diplomas or certificates if the companies are approved by the Norwegian Maritime Authority (Sjøfartsdirektoratet, 2019). On the other hand, comprehensive universities instruct technicians in how to design maritime simulations. There is no overlap between seafarers and technicians. In addition, technicians have less experience working at sea, while the seafarers have less knowledge of the simulators' capabilities and limitations. Altogether, the relationship between competences of individual labours and the above-mentioned missing links among organizations create a gap in which unavoidable fundamental questions are raised over the long term: Who has competence, who defines it, who evaluates it, and which relevant simulators are equivalent to in-situ knowledge and skills of which people in the work setting? Simply put it, the usefulness of scenarios created by simulators is

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uncertain and unstable. This leads to an interesting research question: *How participatory design as a research method contributes to the design of marine technologies, creating scenarios via simulators for example, in turn, to help designing simulation-based maritime education?*

COMPETENCE AND MARITIME OPERATIONS

In line with the research question, another important issue develops—why do we argue over whether utilizing simulators is the only way to train seafarers from a novice to a proficient level, but not to the expert level? The Ministry of Education and Research of Norway, which prioritizes non-cognitive skills and experience-based expertise (Utredninger, 2018), provides a definition: Competence is consistence of skills, knowledge, understanding, and attitude (Sjøfartsdirektoratet, 2019). This means that if an individual wants to gain high competence in his or her field, simply knowing a lot of facts and rules, such as training procedures, provides only a basic understanding of the necessary skills. The person must also know how to find his own way around the knowledge needed in his profession (Dreyfus & Dreyfus, 1988).

Hence, it is noticeable that current simulator-based maritime education in Norway may not be able to offer a platform for seafarers to gain the highest level of competence if there is no suitable methodology. The reason for this is simple; land-based simulators are connected through a machine network to engage seafarers in the training process. Because technicians restrict this network to a predefined class of appropriate responses (cognitive skills of marine operators), the network incorporates the intelligence that was built into the machines by the technicians for that particular context. These skills reflect the competence of the technicians, not the competence of the seafarers. In addition, seafarers must follow the work procedures in their training programme. However, that is not true regarding seafarers' in-situ work practices at sea (Pan, 2018). If that is an issue, should we draw an equal sign between the technicians, seafarers, and trainers in vocational and technical schools towards their contributions in the maritime training? Are the competences of technicians the same as those of maritime authorities and managers? Are the competences of technicians the same as those of maritime trainers at different schools? These are questionable. Can we expect technicians to produce a product that will increase the competences of trainers, authorities, managers, and seafarers? Again, we doubt it. Competence cannot be transferred from one individual labour group to another simply through a fixed simulator. No one can duplicate the working experiences of others to produce the same success stories. However, only one thing can be learned from others: apply the lessons you learn to your daily work practice and obtain experiences to achieve competence.

As Dreyfus and Dreyfus (1988) argue:

... [Stuart] he saw that no matter how much more work was done in computer simulation and operation research, and no matter how sophisticated the rules and procedures become, [the] analytic abstractions would never allow the computer to attain expertise.

In this vein, whether the networks succeed or fail, and whether the final training produces seafarer competence, it remains true that human experts, after years of experience, are able to respond intuitively to situations in a way that defies logic and surprises even the experts and trainers. Thus, if a simulator is not able to function competently, why do we expect the formal training procedures that similar with 'formal mathematical or analytical rationality' (Flyvberg, 2001) of the simulator to help seafarers gain a deep understanding of the competencies that build upon vast successful and non-duplicable experiences? Moreover, why do we only use the results from experimental work to misrepresent experience, another form of competence? Is it fruitful to help designing marine technologies with better and better scenarios? If knowledge bridges among different participants in the simulation-based maritime education is not built yet, then can we foresight future skills in digitalisation era? We would say, no.

Gaining a high level of competence and future skills in an unstructured area like maritime operations seems to require considerable concrete experiences with some type of structure. An individual person will be both an expert in certain types of methods in his or her own area of skill and less skilled in other areas. Being an expert, or being at any particular stage of skill acquisition, does not necessarily mean performing as well as everyone else who exhibits the same type of thought processes. Everyone function in at least one of five stages of skill level: novice, advanced beginner, competent, proficient, and expert (Dreyfus & Dreyfus, 1988). A good proficient performer, such as a technician setting up a fixed simulator, while intuitively organizing and understanding his task, will still find himself thinking analytically about what to do. The same applies to investigators of future skills.

If we accept that we can misunderstand that human skills are not abstract and rule-guided, then it is a time for us to understand that human learning is more intelligence than calculative rationality. Human competence is contrary to logic and reasoning. For example, human behaviour does not always follow rational goals but a vast rationality of "combining component parts to obtain a whole" (Sjøfartsdirektoratet, 2019) or arational[3] behaviour. If such understanding matters, then competent performance is rational, proficiency performance is transitional, and expert action is *arational*.

How do we apply this understanding of the human learning process to the technology environment? How can we bring contributions from all participants to redesign technology (i.e., creating scenarios) and foresight future? We must have a holistic understanding of the competence of seafarers, trainers, technicians, authorities, and managers and their simulator-supported interactive relationships toward decision-making. It is important to bear in mind, as scientists, that your users are not stupid (Maceli, 2011) and that only the designed mechanism of training is, in most cases, the fault of scientists. Thus, participatory design as a research approach respects all users of simulators and can facility a design process for the maritime education. Probably it is not the only approach, but in our view, it is the best way to answer the question of who will evaluate whose competence through which joint agreement of what simulator competence.

WHY HUMAN LEARNING MATTERS IN FORESIGHT FUTURE SKILLS

Looking at the maritime domain, vocational education and technical colleges do train seafarers in gaining cognitive skills[4]. However, cognitive skills are not full competence (Sjøfartsdirektoratet, 2019) and are rule-guided, expressed as "knowing that." If working situation is changed and thus requires new skills, a seafarer might not be able to handle it due to a lack of experience, expressed as "knowing how." This "knowing how" requires us to be broader participants to both build knowledge and exchange experiences. Together, we can build up an ecosystem to help develop competence and value for foresight future skills, including redesigning simulators to better support regulations and organizational restructuring.

What causes the knowledge gap of competence in the maritime domain? Three factors contribute to the gap:

1. Vocational education, technical colleges, and training companies primarily focus on cognitive skills of maritime operations (Dragomir, 2006).

2. Comprehensive universities overlook technology use and its relation to human learning and competence, leading to a mismatch between technology design and technology use (Pan, 2018)

3. Maritime industries have ambiguous rules and regulations that complicate recognition of a seafarer who possesses high competence (Pan, Oksavik, & Hildre, 2019). Although seafarers participate in most education and research activities in the above two types of institutions, they take all results as granted and perhaps with less cognitive justice (van der Velden, 2009).

It is noticeable that the distribution of maritime education is not the only thing that contributes to the gap. The International Convention on Standards of Training, Certification and Watch-keeping (STCW) for Seafarers (International Maritime Organization, 2010) is also accountable. Notably, we do not admit that STCW has done something wrong. Instead, we illustrate that STCW has nothing to do with increasing seafarers' competence but only promises a procedure to train a novice seafarer and bring him or her to the proficient level. In addition, all these levels obey three principles (Flyvberg, 2001) that help describe how things work: the practical level, the component level, and the functional level. These three principles follow basic rules and laws of physics and mathematics. For example, the simulator divides a particular job at sea into different components, each with its own function, and puts them all together to produce a result. This way, mechanistic functions are combined to encompass the functioning of the whole. Such top-down, context-independent (Simon, 1996) analytical methods for cognitive skills (Pan, 2018; Sjøfartsdirektoratet, 2019) are adopted to analyse competences of seafarers along a wide range between novice and proficient (Pan, 2018). For example, using a survey, questionnaire, and tools, we can evaluate human performance in simulators repeatedly until we get a satisfactory result.

The point is that no one can prove how many evaluations are enough because controlled experiments are not able to predict which unpredictable phenomena will cause failures[4]. If we cannot manage what we choose to measure, we will not be able to control the cost of running experiments and will only create digital waste in most cases. All this will disable us from forecasting the usefulness of future skills for seafarers, trainers, technicians, authorities, and managers. As we are able to foresee and devise regulations for selecting future seafarers, it is important to address the transferring of competence through updated simulators. On one hand, we have to deal with participation, competence reuse, and competence transfer, while on the other hand, and decide how to combine these elements to shape simulator development. All these issues are important factors in foresight future skills in the maritime domain in the era of digitalization, artificial intelligence, and human-centred and ICT supported smart maritime operations.

PARTICIPATORY DESIGN

Participatory design (PD), which is a bottom-up and context-dependent research methodology for conducting an action-based study in foresight future skills. This approach enables us to avoid a sole top-down (evaluation-oriented and exploratory-oriented, see table 1) approach so we can focus on how to support the transferring of competence through the supported simulators. We propose our use of participatory design consists of four methods: 1) literature and statistics review, 2) interview and focus groups, 3) scenario-based future workshops, simulation building, and after action review (AAR), and 4) simulation-reconfiguration and user innovation. Although PD is a systematic guideline for conducting design-relevant analysis for the maritime domain, the important matter is the interactive relationships among methods that shape and reshape the results of the study.

Literature and statistic review

Once a topic is chosen and selected as a possible problem or question, it is time to explore what work has been done on this topic, problem, or question. When reviewing literature, you look up all relevant material that has ever been published on your topic. You then familiarize yourself with the literature and carefully recode the information so you can include it in your references. You will learn about the ongoing processes of new knowledge and discoveries that are taking place in your field. There are plenty of published maritime studies that report how seafaring skills are evaluated in simulators. These are importance resources for figuring out the inabilities of both seafarers and simulators. This is a process to investigate the cognitive skills of seafarers in current studies.

A purely literature and statistics review will not provide in-depth answers to how to foresee the future. You will only discover what is missing in a field. Your research will need to fill the gap in the existing field and existing studies or verify previous studies, using a better methodology that refutes, substantiates, or extends existing theory. In addition, the results of PD approach are still part of the cognitive procedure for both the studied seafarers and the people who conduct the study. This means that literature and statistical results can only promise a new round of experimental work in evaluating human performance in automatic, mechanical, and mechatronic-based technology. To foresee the future, one must shift to qualitative methods to understand phenomena in the field from a broader view of marine operations at sea and control and management on land.

Interview and focus groups

Interviews and observation concentrate on the interviewees' personal situations and needs. In particular, the interviewer acts as a moderator and focus groups aim to capture group dynamics (Bergold & Thomas, 2012). The use of interviews and focus groups can help to confirm previous studies and identify the stakeholders who belong to the work settings or organizational context directly related to the simulation.

The personal experiences of seafarers will be brought to the table and be given the same priority when investigating their use of simulators during the training process. These experiences will be taken into account when trainers set up scenarios and guide seafarers to use the simulators. It also helps to investigate whether the trainers' experiences of setting up scenarios and "guidelines" for use with the simulators actually match with seafarers. This matching process is essential for companies to self-compare with their process of crafting rules and regulations for selecting seafarers for specific positions and if the certificates distributed are still valuable. The matching process also increases awareness of the authority to examine whether a certificate can guarantee a "knowing how" ability of the seafarer.

Through exchanging experiences in focus groups, it is possible to negotiate a common agreement of competence. Who owns it, who can evaluate it, how is it evaluated, and what technology is used in the simulator to evaluate it? Remember that future skills are not taken for granted in the era of digitalization and artificial intelligence. Everyone should be ready to review their abilities based on experiences of the past and present to foresee potential skills needed in the future and to shape technology development to support the foresight skills.

Scenario-based future workshops, simulation building, and after action review

After conducting the interviews and focus groups, scenarios can be drawn from the various experiences of the different participants. In this manner, scenario-based future workshops can be arranged to study the various types of future knowledge and skills needed for the participants. This process can also help identify related tasks, needs, and solutions, and helps in the redesign of simulations that scope out future knowledge and skills from all participants.

Prototypes can be made to address concerns from participants. Technicians and participants can co-design the simulations. Next, we can immediately hold an after action review (AAR) that enables all participants to describe whether they are satisfied with the results at this stage. Could they still use their experience to achieve a new competence in their field? If so, the use of AAR can help us develop collaboration and help in testing the practical technical integration of seafarers into the decision support process for dynamic resource allocation. This allocation of resources can be used in group meetings and workshops with other participants, such as those who are not able to participate in such a process.

Simulator-reconfiguration and user innovation

The above processes help us focus more broadly on developing collaboration more than we have anticipated. The reason is simple. Training seafarers in simulations and foreseeing their future skills are strongly based on simulator-based technology. Without reconfigured and updated technology, it is impossible to draw a line between past and future skills. We must also focus on collaboration between participants because future skills benefit from a joint agreement among different participants in simulator-based training. Thus, we should create a platform that treats all participants as equal as much as possible and encourage them to innovate together through the platform toward a joint agreement. It is definitely about designing and redesigning simulations, simulators, and the experiences of organizations.

Bear in mind that, though this is not the last stage of foreseeing future skills, it may be a new point of departure. Foresight future skills are not a static activity but a dynamic process. We should prepare an iteration process toward innovation with simulation and, most importantly, with the people who use and design the simulations. Innovation is not just about product innovation, it is a process of sustainable growth. Participants must better integrate product innovation with their research, business, and market models into the process and service innovations (Govindarajan & Desai, 2013).

POSITIONING PD IN SIMULATION-BASED MARITIME EDUCATION

Identifying prerequisites for stakeholder participation

If the joint work processes and the simulator support of the participants' engagement initiatives do not work together successfully, consequences in different areas, not the least of which in the maritime domain, can be devastating. Participant participation in design is crucial and must be able to handle substantial practical challenges. Since resource scarcity at different organizations lies behind the majority of the initiatives, limited time and organizational resources are usually set aside for participant participation. The issue is further complicated by the fact that seafarers and many other important participants do not operate in an organizational context. In our experience, both these circumstances were apparent in the difficulty to retain a coherent design group over time. The reason is due to a misunderstanding of human learning and misuse of research methods and techniques from the natural sciences to the maritime domain. Let us interpret this idea further.

Learning from the past to handle the future

In light of societal development, the role of contemporary PD is not primarily protecting participants from alienation and ergonomic delicense of technology nor is driven by ideological values of workplace democracy. A pronounced defensive approach no longer makes sense. On the contrary, the simulator itself has become a tool for empowerment and increased transparency between educational institutions, training schools, authorities, and the shipping companies. In a wider perspective, the PD approach can be seen as a chance for researchers to bring political values to the forefront, as they not only encourage organizational efficiency and redundancy motives, but also clearly develop the skills and competences of the seafarers involved. The PD approach can be an important means to increase opportunities for seafarers, letting them interact and propose design solutions that in the long-run will benefit and increase the very same initiatives. This helps seafarers contribute to decision making and play a more emphasized role. For this development to take place, we need a discourse focusing on how the PD approach can be used to allow seafarers to build or re-configure systems that are more effective.

As described, we note how PD is not exclusively or primarily about simulation artefacts but is equally about improving collaborative settings and processes. Such practical solutions involve an initial broad organizational focus involving participant identification and involvement, defining and negotiating tasks and responsibilities, handling legal aspects, and introducing interdisciplinary perspectives and multifaceted development teams. It seems plausible that PD in similar institutional transformation maritime contexts will not only experience similar challenges but will also need to address them similarly. In addition, sufficient time and resources must be spent on organizational analysis and early design. Given the resource-constrained character of the environment, the major related PD challenge will likely persuade maritime authorities on long-term returns on investment in participant participation to enable them to provide the means for experience. Studies focusing on potential cost-benefits of applying PD is a way to address this challenge. Organizational analysis requires substantial time and effort to enable proper technology development. It has been suggested that PD should focus active participant participation where it is most needed (e.g., in needs analysis and iterative design).

In our experience, it is evident that the PD process is primarily about development of new collaborations, new tasks, and identifying basic equipment needs. We perceive simulator reconfiguration and development of participant innovation as rather straightforward once organizational and ethical issues have been addressed. It was thus possible to balance the more intensive and resource-demanding initial efforts with more concentrated work around simulator re-configuration and extension, once central issues of the collaboration have been addressed. The study of participant innovation in relation to maritime studies concluded that in order to properly foresee future skills, we must involve everyone who designs and uses simulators to make decisions during the process. The conditions for participant innovation were more favourable where PD gradually turned in this direction. With growing experience, participants can add functionality to the simulations as part of their first responder engagement. They also successively adapted functions to overcome legal obstacles and technological constraints. In other words, simulators and PD can be combined to enable participant empowerment, take active part in re-configuration, and propose their own design solutions. A necessary step in this direction is adopting guidelines for PD to develop situated applications and make them open to meta-design and re-configuration.

Combing qualitative research methods in situated contexts

In any design context, it is crucial to address identified challenges by targeting the approach and design techniques to the current situation or project. Over the decades, numerous methods for active user participation, techniques, and tools (e.g., organizational games, role-playing games, organizational toolkits, future workshops, storyboarding) have been applied, used, and evaluated in research. Also, qualitative ethnographic inspired methods, such as contextual inquiry and interpretation sessions, have been applied. However, in the current maritime context, many of the above methods and tools have not been practiced. Therefore, retaining a design group with active participant participation in a short period of time can be an option. For instance, when training seafarers in simulators, debriefing sessions can involve other participants to foresee future skills and discuss present experiences. As to qualitative methods, contextual inquiry is possible to accomplish when the common context is identified and clear to the participants and when ethnography in general presumes an organizational setting or existing situation to study.

A scenario-based future workshop and an exercise AAR can explore new possibilities for maritime domain in foreseeing future skills. It may be argued that interviews and focus groups, even though the latter are similar to design groups, are data collection methods that enable user representation rather than active participation. In retrospect, we perceive that focus groups directly suggest many users' needs. They also provide the necessary baseline for a collaborative setting and expose how much was not set in the project's context in terms of tasks, responsibilities, legal matters, etc. This made it possible for us to plan the remainder of the study and extend our design team accordingly. Taking this together with our past experience, the PD perspective seems suitable for future work in the maritime domain, as a replacement or complement to the current design method for foresight skills and knowledge as well as the maritime education.

In addition, many basic needs and simulation requirements emerged first in the simulated "real" situation. It may be argued that real exercises are costly and resource consuming. On the other hand, we deem them as extremely valuable when the situated context is new to the participation. As for AARs, they are not part of traditional toolboxes but are explicitly used for participant feedback. We believe that the AAR elaborates and explains many of the things that have been observed during exercises from a group perspective in identifying and elaborating on the participants' needs.

REFLECTION ON UTILISATION OF PD IN THE DIGITALISATION ERA

Our experience is based on project examples taking place in the Norwegian maritime domain. The study should be viewed as a contribution to the ongoing debate on new methods, addressing how a planned approach can be successively and pragmatically modified and applied to foresight future skills in the maritime education, both for training seafarers and educating technicians, mangers and trainers. Of course, any project will need to do its own modifications and every final combination of methods will depend on the specific project context. Of course, we do not claim to solve all potential challenges associated with our approach, but rather we provide some suggestions as to how they may be approached. In many respects, the related work in similar maritime settings points to similar challenges. It has been difficult practically to involve the participants over time using the traditional engineering design approach, the same difficulty applies to the PD approach too. Therefore, in the cross-sector setting involving semi-professionals in collaboration with the universities, we have to choose carefully who will be the participants and the possibility to be engaged to integrate the new collaborations and include the development of simulations through the experience at sea.

However, there is a long way to go since a well-established research group is needed. Historical issues caused the gaps of maritime education in higher education and have already leading to unsystematic structure for research and development of maritime technology. Well, the most bogeyman problem is to unfruitfully picture an incomplete work practices of participants. For example, Mallam et al. (2017) designed an 'ergonomic ship-evaluation tool' for introducing participatory design as a method to design a ship. The tool can create an environment that will help naval architects, crews and ergonomists work together to develop human-centered design solutions for physical work environments. The tool grapes the crews demand rather than what their work practices are in reality.

While, the central concern with in PD is to deal with the relation between studying the work practices of the workers from whom new technologies are being developed and directly engaging workers in design (Jeanette Blomberg & Karati, 2013). Thus, it is too dangerous to only utilise a piece of PD and overlook another part. Furthermore, it is a challenge to conclude that there is a human-centered approach in the maritime studies (Costa, Lundh, & Mackinnon, 2018; de Vries, Hogström, Costa, & Mallam, 2017; Mallam, Lundh, & MacKinnon, 2017a) although a few researchers claim such concept elsewhere.

The focus of PD in the digitalisation era

If there is an advantage to utilise PD in the maritime studies, we should know what is PD about. According to Blomberg and Karasti (2013, p. 89):

Participatory design has been defined by its insistence that worker's knowledge is available to shape design directions by providing places and spaces for interaction between designers and practitioners that do not privilege one kind of knowledge over another.

PD brings unique experiences and perspectives when people mutual learn from others' domain of knowledge. Everyone who participates in the design process has a voice that can be heard and be considered during the design process. This is a vital point for controlling the quality of a research and development project.

Now, with the increased concerns of safety maritime operation, designers are pushed to seek most appropriate approach to deal with such interests. However, we have to warn that it might be good to make visible participants' situated methods for creating the coherence of phenomena, such as applying the studied results from ergonomists regarding the traditional engineering design work, however, we lose the opportunity to describe phenomena using participants' categories and organising frameworks.

digitalisation as a concept but a term we use to describe the era of digitalising, autonomous, and many other promising words which are omnipresent used in the maritime sections, including shipyards, maritime consulting, maritime education, and crew management and so on. Due to non-existing systematic approach in the maritime domain, one could not find in-depth discussions regarding how technology can be and should be implemented in the maritime domain. PD can bring changes that is defined by the interests of workers, the requirements for their work, and the jointly negotiated path to change. Although researchers, developers, managers and others in the maritime domain might have different expertise and favourite in their own fields, they could find their ways to make the project more sustainable. As Bødker et al (Bødker, Kensing, & Simonsen, 2004, pp.140-141) remarked:

Good IT design requires knowledge of work practices in order to determine which company traditions are fundamental and sustainable, and which are outdated. Put in a different way, only when a design team has fundamental knowledge of existing work practices can it arrive at what we call a 'sustainable design'.

In this case, in the digitalisation era, all participants are the actors to shape the future in the maritime education. Maritime education may no longer only about engineering, electrician, management, and training, it becomes complex and with less clear boundary with other courses. That means everyone becomes co-designer and must opportunities to see first-hand, participant in, the life of the user participants. This is essential for the maritime education for the future skills. What competence should one to have in the digital era?

The change for the simulation-based maritime education

In order to better prepare for the future, we need to include studying phenomena in a systematic way of participants in their everyday settings, taking a holistic view, providing a descriptive understanding, and taking a member's perspective (Blomberg, Giacomi, Mosher, & Swenton-Wall, 1993). Therefore, there is no necessary to distinguish who is providing what types of maritime education but we can see them as a completely organisational system, including humans, technological artefacts, and institutional rules for organising humans and technologies together.

The starting point is always to find a way of providing socially enriched understanding of current work practices that is fruitful for designing simulation-based maritime education. It is firstly important to respect for the different knowledge that seafarers, engineers, technician, manager, and designers bring to PD project. In this manner, we could commitment to a members' perspective that focuses on gaining an insider's view and using terms relevant and meaningful to the people who use simulators. This is the best way to create opportunities for designers and workers to learn about each other's domain through direct interaction for co-creating situations where seafarers can experience the design possibilities and encounter first-hand experiences.

Secondly, it is also important to have a holistic view of how the outcome of the design that may affect the work practices of all participants. For example, changes in creating a scenario of maritime training that may request an impact on the engineering, design, teaching as well as management skills.

Thirdly, describing current situation is important to prescribing a change. This is because without better knowing current situation is a vial resource to anchor change in the past and present, and offering all participants a limit scheme for the future imagination. For example, in the early work of PD, researchers show that users with their own knowledge and experience can provide a perspective on their everyday work practices, often in the context of envisioning new artefacts and ways of working (Kyng, 1995).

Fourthly, since everyone is participating in designing scenarios-based maritime education, everyone is co-designer and must have opportunities to see first-hand, participate in, the life of the maritime education. The participatory designer, in this unique situation, can engage in a continuum of 'roles' with the ability to cycle between participation in the life of all simulator users and looking for new possibilities for changes.

Education providers as mediators

With our lengthy discussion of the contribution of PD, we recognise the importance of re-scrutinizing the role of educational providers in the maritime domain. We need to stress that educational providers are mediators between the workplace and the design intervention for simulation-based maritime education. In this manner, simulators are not only products one developed for others to use. Also, simulators are not one who can only use for teaching purposes. We must acknowledge that simulation is only a tool that is used to support humans cooperation, collaboration, and maybe competition. However, without mutual learning process, we cannot confidently state that the non-transferable skills of different experts in their own fields can be grounded firmly via simulation-based maritime education. Thus, it will be a challenge for using simulator as a tool to promise educational goals, including training for the future.

In such consequence, education providers have to shift their positions from only providers' position to the positions of mediators. In tradition, educational providers only provide either educating people to design technology, or training people to use technology (see Figure 1). This single way of education cannot promise simulator-based maritime education will help seafarers to be professionals; neither can help other participants have a clear and complete direction of maritime development. This is understandable that maritime domain was and is following the development of normal science (Kuhn, 2012), following the cognitive processor (procedure learning) (Card, Moran, & Newell, 1986) rather taking humans learning into account, which might base on intimated knowledge of several thousand concrete cases in peoples own area of expertise (Flyvberg, 2001). PD has contributed to change and offered an approach to help linking back the knowledge of work practices to the design of technology (see Figure 2).

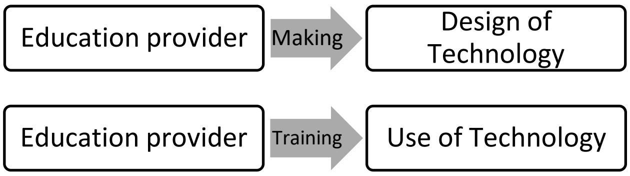

Figure 1: The role of education provider in the traditional maritime domain

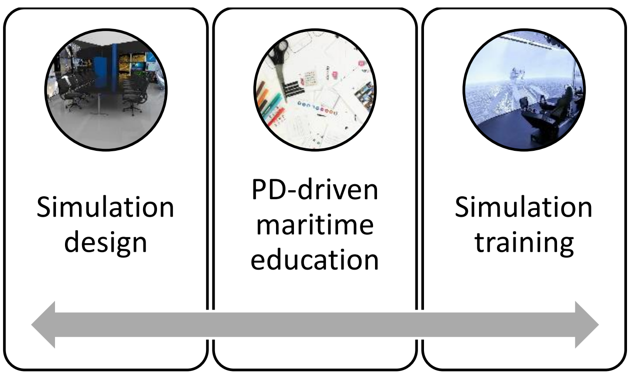

Figure 2: The role of education provider in PD-driven maritime domain

In this process, PD can help avoiding useless repetition of evaluation of training results, not to say its limitation of identifying ones true expertise. Instead, PD shifts our focus how to bring those expertise in the cycle to design. Winograd and Flores (Winograd & Flores, 1986, p. xi) add:

We encounter the deep questions of design when we recognize that in designing tools we are designing ways of being.

Design is, fundamentally for us, about designing futures for actual people. If people wish to encounter digitalisation, autonomous and other attractive activities in digitalisation era, we must agree that it is simulation-based maritime education is a system where PD can facility different techniques to make innovation for the maritime domain, especially focusing on the future skills and competence in the digital future.

Hence, in the end, we suggest three tips for the maritime domain for implementing PD-based maritime research and development.

- For education providers, a trained ethnographer can help to mediate simulation use and design. A trained ethnographer can co-realise (Forsythe, 1999) what observed in reality and design in simulation will best match the need of all participants.
- Case-based scenario making can help support of re-conceptualizing and restructuring how maritime training and engineering work (simulation design) should be undertaken. PD helps to filling the distance between the missing area of competence in the maritime domain. This activity builds up a life-cycle development of competence and value for foresight future skills.
- PD informs maritime studies as interdisciplinary research area. PD is valuable in making visible 'multiple communities' in the maritime studies and do not leave 'distance area' for unmeasurable expertise in the design process. Instead, PD allows creating a disciplinary division of labour, the differing expertise complementing one another. In this view, interdisciplinary is seen as a functional activity can be viewed as seeking its own ways of representing 'methodological' positions of different fields to work in a common place for making innovation.

Through the PD perspectives, we assume that rebuilding the knowledge base and practice in the maritime structure for shaping a healthy research and development platform is an advantage. The PD perspective could do this, and the maritime domain urgently needs it.

CONCLUDING REMARKS

Although this is a point of departure for discussing how participatory design can play a role to develop a methodology for foresight of future skills in the maritime domain, we find there is huge potential to restructure maritime education and research as a basis to support foreseeing competence of maritime personnel. In the article we argue that using a bottom-to-top model to forecast human capability we can redesign key features of future skills, as well as processes of linking past and current skills and knowledge to future needs. Through the process of the PD approach, many participants from industry, research institutions, training companies, and authorities could cooperatively offer valuable insights into structuring the future. This collaborative approach is one characteristic of the foresight exercise that achieves consensus on shared visions and commitment to the results. The most required of us is to deploy this approach speciously into practice to improve simulation-based maritime education and training for the benefit of the future maritime labour force in Norway.

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NOTES

1. Lykkeland is a TV program lunched on NRK TV series from 2018. The TV program is about when Phillips has found the largest subsea oil basin in history, everything in Norway is about to change.
2. Digitalization means that business uses technology to engage with people to address precisely their particular needs. However, a phony of digitization is widely cited in industries, which, on the contrary, aims at increasing the efficiency of technology processes. Our understanding of digitalization follows the former definition.
3. *Arational* is an adjective term and means a behavior or action is not based on or governed by logical reasoning.
4. Cognitive skills come from the procedure learning. There are four stages of procedure learning. First, cognitive processor is 'programmed' with procedural knowledge acquired from learning. Second, at first procedures are declarative knowledge from problem solving (trial and error) and explicit instructions (through comprehend instructive material). Third, with practice, converted into procedural knowledge one can routinely executed to achieve goal to gain a routine skill. Forth, with extensive practice, a skill becomes automated – you can perform procedure automatically.

REFERENCES

Bergold, J., & Thomas, S. (2012). Pariticipatory research methods: A methodological approach in motion. *Forum Qualitative Sozialforschung, 13*.

Blomberg, J., Giacomi, J., Mosher, A., & Swenton-Wall, P. (1993). Ethnographic field methods and their relation to design. In *Participatory design: principles and practices* (pp. 123–155). London: Lawrence Erlbraum Associates.

Blomberg, J., & Karati, H. (2013). Ethnography: Positioning Ethnography within Participatory Design. In J. Simonsen & T. Robertson (Eds.), *Rouledge International Handbook of Participatory Design* (pp. 86–116). New York and London: Routledge.

Bødker, K., Kensing, F., & Simonsen, J. (2004). *Paticipatory IT Design: Designing for Business and Workplace Realities*. Cambridge, MA: MIT Press.

Card, S. K., Moran, T. P., & Newell, A. (1986). The Model Human Processor - An Engineering Model of Human Performance. In *Handbook of Perception and Human Performance, Vol. 2: Cognitive Processes and Performance*.

Costa, N. A., Lundh, M., & Mackinnon, S. N. (2018). Identifying gaps, opportunities and user needs for future E-navigation technology and information exchange. In *Advances in Intelligent Systems and Computing* (Vol. 597).

de Vries, L., Hogström, P., Costa, N., & Mallam, S. (2017). Designing for safe operations: promoting a human-centred approach to complex vessel design. *Ships and Offshore Structures*, *12*(8), 1016–1023.

Dragomir, C. (2006). Norwegian initiatives to improve maritime education and to motivate young generation join seafaring. In *Advances in fiscal, political and law science.*

Dreyfus, H., & Dreyfus, S. (1988). *Mind over machine: The power of human intuition and expertise in the era of the computer*. NY: Free Press.

Flyvberg, B. (2001). *Making social science matter: Why social inquiry fails and how it can succeed again*. London: Cambridge University Press.

Forsythe, D. E. (1999). "It's Just a Matter of Common Sense": Ethnography as Invisible Work. *Computer Supported Cooperative Work (CSCW)*, *8*(1), 127–145.

Govindarajan, V., & Desai, J. (2013). Innovation isn't just about new product.

H.A., S. (1996). *The sciences of the artifical*. Cambridge, MA: MIT Press.

International Maritime Organization. (2010). International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). Retrieved September 24, 2018, from http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-on-Standards-of-Training,-Certification-and-Watchkeeping-for-Seafarers-(STCW).aspx

Kuhn, T. S. (2012). *The Structure of Scientific Revolutions* (4th ed.). Chicago: University of Chicago Press.

Kyng, M. (1995). Making representation work. *Communications of the ACM*, *38*(9), 46–55.

Maceli, M. (2011). From Human Factors to Human Actors to Human Crafters: Principles Supporting Design in Use. In *Human Factors in Computing Systems* (pp. 1–4).

Mallam, S. C., Lundh, M., & MacKinnon, S. N. (2017a). Evaluating a digital ship design tool prototype: Designers' perceptions of novel ergonomics software. *Applied Ergonomics*, *59*, 19–26.

Mallam, S. C., Lundh, M., & MacKinnon, S. N. (2017b). Integrating Participatory Practices in Ship Design and Construction. *Ergonomics in Design: The Quarterly of Human Factors Applications*, *25*(2), 4–11.

Pan, Y. (2018). *From field to simulator: visualizing ethnographic outcomes to support systems developers*. University of Oslo.

Pan, Y., Oksavik, A., & Hildre, H. P. (2019). Making sense of maritime simulator use: A multi-case study in Norway. *Technology, Knowledge and Learning*, *Submitted*,.

Sjøfartsdirektoratet. (2019). Maritime Education and Training Institutions. Retrieved March 18, 2019, from https://www.sdir.no/en/shipping/seafarers/education-and-training/

Utredninger, N. offentlige. (2018). *Kunnskapsgrunnlaget Fremtidige kompetansebehov I.*

van der Velden, M. (2009). *Another design is possible: Looking for ethical agency in global information and communication technology*. University of Bergen.

Winograd, T., & Flores, F. (1986). *Understanding Computers and Cognition*. New York: Addison-Wesley.

Virtual Reality as a future training medium for seafarers: potential and challenges

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Abstract - **The field of wearable technologies has evolved greatly in the past few years. Virtual Reality (VR) Head Mounted Displays (HMDs) are an emerging technological trend among the wearable technologies and promises to revolutionize the way people learn. Due to their ability to provide highly immersive and engaging experiences, VR based simulators are quickly becoming indispensable part of modern professional training. Nevertheless, VR still has to address many challenges and overcome the limitations before being adopted as training simulators. This paper aims to perform a brief analysis of the potential of VR in maritime training and possible challenges in adopting the technology from human factors, innovation and technology point of view for a holistic perspective. An initial investigation of the technology acceptance of VR engine room simulators among marine engineering students was carried out through an empirical study and the results are also presented in the paper.**

Keywords
Immersive VR, Maritime education, Technology Acceptance Model, Shipping, Simulator training

INTRODUCTION

Maritime transport is a highly globalized, multi-cultural, technology-oriented industry that has significant impact on the global economy. Like any complex socio-technical systems, safety is paramount in maritime industry. Highly trained, skilled crews are one way to enhance safety in the industry (Berg et al. 2013). Maritime Education and Training (MET) has traditionally utilized a combination of theoretical education and practical, hands-on experience at sea. With the convenience of maritime simulators, increasingly more practice-oriented training is occurring in bridge and machine room simulators (Nazir et al. 2015). Whether it is simulation or training on-the-job, the key outcome expected from training is the transfer of skills from training environment to the real work environment.

Simulators provide a safe and cost-effective alternative to on-the-job for acquiring skills. Training simulators allow students to make errors and learn from their mistakes in a controlled environment, free from real-world consequences (Salas et al. 1998). Simulators have been an integral part of the MET for more than 50 years. Maritime simulators have constantly been evolving, improving over time as the enabling technologies improve. Current technological advancements in computer processing power, graphics processing and image modeling has given the simulator developers the ability to make realistic simulations with a high level of fidelity.

With the introduction of advanced and cost-effective VR Head Mounted Displays (HMDs), VR technology prmises to offer high quality, immersive simulations at a relatively low cost compared to traditional simulators. In recent years, immersive VR simulators have been increasingly developed and applied in various fields including the maritime transport. Currently there are many efforts within the maritime industry to develop VR training simulators.

VR TECHNOLOGY

Virtual Reality is when a person ceases to perceive one's own surroundings and experiences the computer-generated environment immersed through a dedicated headset, or an array of display walls (Freina & Ott, 2015). VR is described by the following three characteristics,

Interactivity: The graphical images must respond in real-time to the user's commands.

Immersion: The user must be drawn into the simulation by sensorial experience.

Imagination: the user's imagination must be free to explore the simulated world to see, touch, move and experience things in new ways from new perspectives. Through this experience, the user can find creative solutions to problems, and new ways of seeing and doing things (Logan, 1998). VR allows users to interact with a computer-generated world, where the user's natural sensory perceptions are

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replaced with a digital three-dimensional (3D) alternative.

VR technology as it might appear is not new. It was conceptualized at least 65 years ago when Ivan Sutherland proposed ‘the Ultimate Display’ (Sutherland,1965). The first commercial VR HMD was launched in 1985 (Burdea & Coiffet, 2003). Throughout the late 80s and 90s there have been several attempts to make VR a consumer product. The beginning and mid 90s saw many efforts to make VR popular but the technological limitations and cost of the HMDs at that time restricted VR to only laboratories and arcades.

Post the introduction of Oculus rift in 2011, Head Mounted Display (HMD) based VR has gained lots of popularity and has become a rapidly growing consumer product. Since then VR has also become more affordable and accessible (Velev & Zlateva, 2017) . This has led to an increased interest in its industrial applications especially in training.

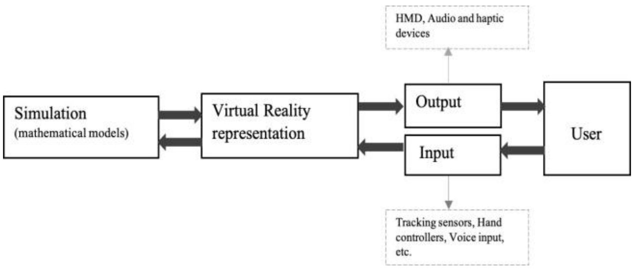

Figure 1. Generic model of virtual Reality simulation

Fig 1. shows how VR based simulation works. The VR system consists of Input and output devices and is connected to the mathematical models of the simulation. User interacts with the VR system through the Input and output devices and the virtual environment in the simulation is updated almost in real time according to the inputs.

State of the Art

A Head Mounted Display is the main component of the current VR technology. The quality of the HMD and the content shown dictates the level of immersion that the users experience (Buttussi & Chittaro, 2018). Vision being the most dominant of all the human senses, a high-quality HMD in a VR system is crucial for providing high immersion. Immersion is also heavily influenced by how users interact with the content and how the VR system stimulates different senses of the users: the more real world sensory stimuli VR replaces, the better the immersion. Binaural sound (spacial audio), haptics (tactile devices), smell (olfactory instrument), and feel of motion (motion platforms) are the other sensory stimulations that will increase the immersion of a VR system to the next level.

The main difference of VR over other traditional mediums is that the point of view of the content in VR is personalized for each user. In order to achieve this, a VR system should have 6 degrees of freedom (DOF) of the head movement as shown in figure 2.

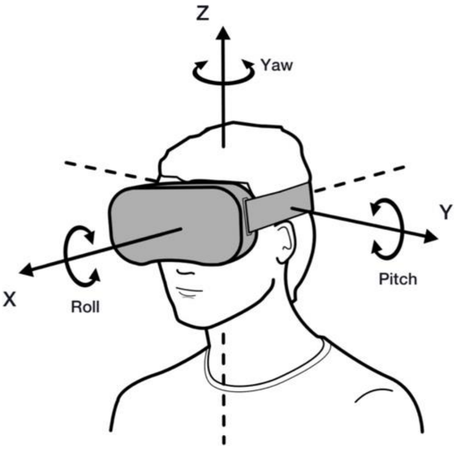

Figure 2: Six DOF in VR

Older VR systems had poor tracking of head movements, lower display resolution and high latency of scene update due to slow computing power. This caused poor VR experience to the users. Also, VR systems were very expensive and bulky due to the limitations of enabling technologies at that time. But the current VR technology has improved a lot in the past few years in all aspects of the system. VR technology now includes low latency, high resolution displays, powerful computing and graphical processors in a compact, portable package.

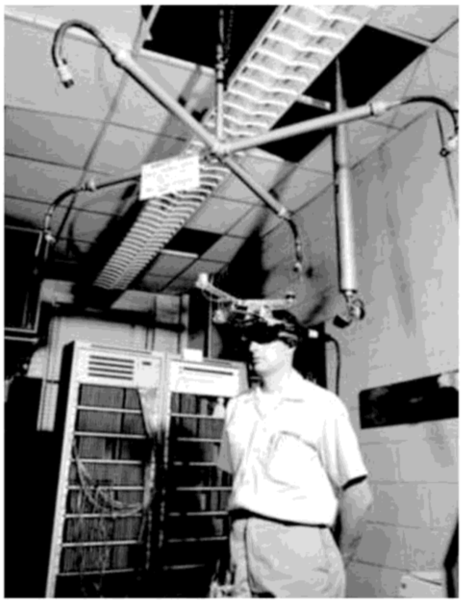

Figure 3 Sword of Damocles by Ivan Sutherland (First computer connected VR system)

Figures 3, 4 and 5 shows the state of the art of VR technology in different period of time.

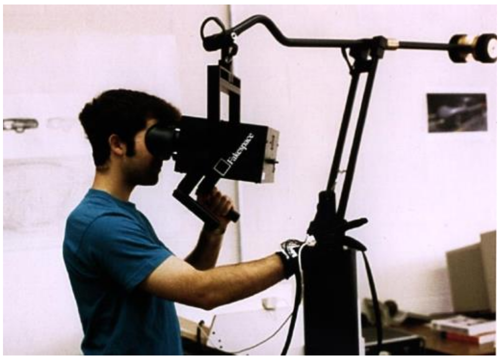

Figure 4: Boom VR by Fakespace

Figure 5: Oculus Quest - Fully standalone VR Headset

VR training simulators

The applications of VR in training are immense (Psotka, 1995). Virtual Reality simulators are quickly becoming indispensable in modern professional education (Farra et al. 2015; Nazir et al. 2012). VR provide many affordances such as three dimensional immersion, Frames of Reference and multisensory cues that are useful for learning (Salzman et al.,1999) and argued to have clear benefits for using in education (Pantelidis, 1995). Due to their ability to provide immersion close to a full scope simulator at a fraction of the cost, VR HMDs are penetrating the professional training fields (Freina and Ott, 2015). This makes VR HMDs interesting for maritime training where simulators are imperative to train seafarers.

Figure 6: A student training in VR simulator

Technology and Generation N

The generation entering the workforce now are considered as 'digital natives' (Prensky, 2001). This 'digital natives' depicted as generation N grew up with technologies such as computer, internet, smart phones. Due to the nature of these technologies, video games and rewards this generation grew up with, they have different formative years than previous generation and this leads to different belief systems (Carstens and Beck, 2005). Generation N relies on hands-on style of learning which is not necessarily in linear fashion (Feiertag and Berge, 2008). They are more engaged through active learning, effective experiential processes such games, hands-on experiences and simulations (Sweeney, 2006). In order to be relevant and keep the younger generation interested and motivated, it is important for the MET to take up new pedogogical tools and methods enabled by technology.

Learning theories

MET has historically been an informal apprenticeship based upon the on-the-job training on board ships (Kennerley, 2002). International convention on Standards of Training, Certification and Watchkeeping (STCW) sets the minimum requirement of seafarer competence (STCW, 2011). MET is designed to provide specific education, training and assessment necessary for seafarer according to STCW. MET now is predominantly competence-based training, which is taught and practiced in classrooms, simulators and on-board training.

According to Bloom's revised taxonomy, there are six levels of intellectual development: Remember (level 1); Understand (level 2); Apply (level 3); Analyze (level 4); Evaluate (level 5); and Create (level 6); (Bloom, 1954). Traditional MET learning practices begin at the lower levels of Bloom's taxonomy, starting with memorizing information in classroom education and building knowledge and skills by slowly moving to higher levels at the end of the education period. On the contrary, VR offers more interactive, and immersive learning and let the students learn by actually performing the tasks (Chen, 2010). It allows the learners to visualize, interact and experience the 3D virtual environment, articulate their understanding of a phenomena by manipulating the virtual environments. Experiential learning and constructivism are the two learning theories VR based learning is based upon (Pantelidis, 1995). Given the hands-on learning preferences of the younger generation of students, VR makes strong case to be investigated for adopting it in MET.

CHALLENGES

In order for experiences with VR headsets to be sustainable and appropriate for long-term use in education and training programs, it is critical to investigate the practicalities of implementing such a technology. As virtual reality becomes more and more mainstream, its role in user/trainee motivation and the overall Quality of Experience in VR become important question to be addressed.

In the recent years, the focus in VR development has been to increase the level of immersion offered by the HMDs through increasing the technical standards of the VR systems while very limited focus was on the actual user experience in the VR. Considering the users are immersed in the virtual environment and their multiple senses are stimulated, a poor VR experience could potentially cause physical and mental discomfort.

Human Factors in VR simulators

For the human factor issues, the physical and psychological effects of VR technology on users and general usability issues are discussed through the available evidence from the literature. The human factors issues in adapting VR simulators mainly fall within physical effects, Usability issues, psycho-logical and social impact of the technology on the users.

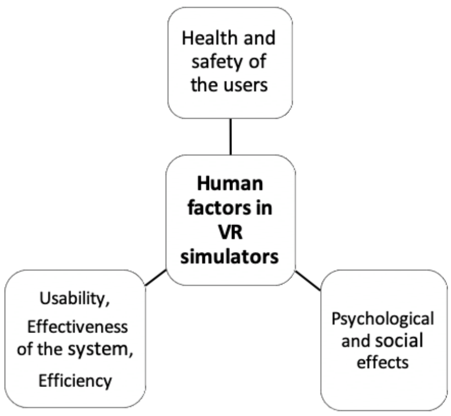

Figure 7: Human factors in VR simulators

Physical effects

The physical side effects of using VR are categorized into three classes:

- Light headedness, Disorientation and disturbed balance
- Nausea
- Ocular issues: eye fatigue, eye strain

Lightheadedness is a feeling of dizziness that causes imbalance in a person. Named as cybersickness, the physical side effects of VR is similar to motionsickness with symptoms reported to include nausea, vomiting, eyestrain, disorientation, ataxia (postural disequilibrium), and vertigo (La Viola Jr, 2000). In addition, aftereffects of VR exposure include symptoms such as postural control changes, perceptual-motor disturbances, flashbacks, drowsiness, fatigue, and locomotion disturbances (Rolland et al. 1995; Stanney and Kennedy, 1997). According to sensory conflict theory, passive movement creates a mismatch between information relating to orientation and movement supplied by the visual and the vestibular systems, and it is this mismatch that induces feelings of nausea. Although some people suffer from a similar motion sickness called simulator sickness in traditional simulators, cybersickness caused by VR could be 3 times stronger (Stanney and Kennedy,1997; Stanney et al., 1997). This is a significant concern as this could limit the application of VR in training and education in general.

The current state of VR technology requires full covering of both eyes with display system that totally isolate the users from the visual and aural stimuli from the real world. Ophthalmologists and vision scientists warn that using VR headsets could lead to the development of myopia (Mon-Williams et al., 1993). However, a direct correlation between VR usage and myopia is not established yet (Turnbull and Phillips, 2017) and is still an ongoing area of research. These physical side effects of VR couldn't be neglected as they will be critical deciding factors for the adaptation of VR in education.

Psychological side effects of VR

Besides the physiological effects, immersive VR can also have direct effect on the psyche of the users. Higher immersion and manipulation of sensories using artificial stimuli in VR could lead to some negative psychological effects. For example, VR increases dissociative experiences and lessens people's sense of presence in actual reality (Renaud, 2015). Renaud further claim that the greater the individual's preexisting tendency for dissociation and immersion, the greater the dissociative effects of VR (Renaud, 2015). Addiction, desentitisation and social isolation are found to be the main psychological side effects of VR. Although not directly relevant, it is important to consider these effect while designing VR based education tools for the ethical reasons.

Usability of VR system

Usability is defined as how well and easily a person can use different functions of a product to perform certain tasks. As a new learning technology, VR simulators need to be thoroughly investigated for any potential user problems. VR is still relatively a new type of Human Computer Interface (HCI) where the users are immersed and interact in 3D. Formal understanding and evaluation of interaction within VR is problematic due to the limited understanding of HCI in immersive 3D (Bowman et al.,1998). Traditional usability evaluation techniques such as heuristic evaluation (Nielsen, 1993) and cognitive walkthrough (Wharton et al, 1994) do not cover all usability issues in VR environment (Sutcliffe & Kaur, 2000). This is due to the egocentric interaction in immersive VR while tradional HCI is from an exocentric frame of reference (Stanney et al.,1998).

Currently there is no usability guide for designing VR user interfaces. This makes VR simulator development much more challenging for simulator vendors and educational researchers.

TECHNOLOGY MANAGEMENT AND USER ACCEPTANCE OF VR TECHNOLOGY

VR is viewed as a distruptive technology in education and training (Psotka, 2013). However, the success of VR as a training medium depends upon how technology addresses the innovation barriers and the extent to which end users accept the technology.

Barriers to Innovation

In the previous attempts, VR technology failed to reach the critical mass of adapters as an innovation to be sustainable. There were many reasons for this failure, but the main factors are cost and immaturity of the enabling technologies for VR systems. The Diffusion of Innovation theory by E.M Rogers (see figure 8) is useful to explain how VR innovation failed earlier and how this could be different this time. Rogers defines diffusion as "the process in which innovation is communicated through certain channels over time among the numbers of a social system" (Rogers, 2003). Rogers categorizes the adapters of innovation in a social system as innovators, early adopters, early majority, late majority and laggards (Rogers, 2003). Innovators are the one pushing forward new ideas to the society. Early adopters are 13.5% of the social system, have the highest level of opinion leadership and serve as a role model for the rest of social system to follow whenever new innovation emerges in the society (Rogers, 2003). The VR innovation was not ready for the society to adapt previously, since it did not go past the early adapters.

VR HMDs for various devices such as computers, gaming consoles and mobile phones are becoming very popular. Commercial VR headsets are available now for 300 to 800 USD and there are more VR contents available now than ever before. However, VR technology still is in the early adapter stage. For VR to be a sustainable technology, it should reach the early and late majority of adapters of the social system as they represent the majority of population. In VR's case, the diffusion relies a lot upon the technology acceptance among the users. In the maritime training context, in order for the VR simulators to be successful, VR technology should be accepted by all the stakeholder in MET such as students, teachers, educational researchers, simulator developers and the maritime industry in general.

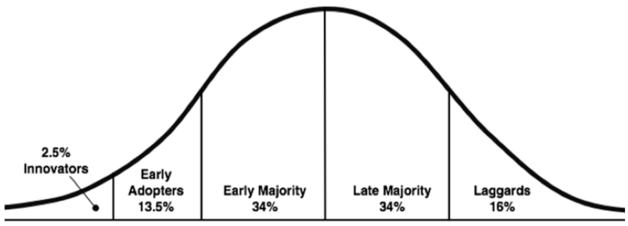

Figure 8: Diffusion of Innovation (DOI) Theory by E.M. Rogers (Rogers, 2003)

Technology Acceptance

The Technology Acceptance Model (TAM) is recognized as one of the most powerful models for studying the acceptance of new information technology (Shen and Eder, 2009). TAM suggests that when a new technology is introduced to the users, a number of factors influence their decision on using them. The model proposes that an individual's perception of ease of use and usefulness are significant factors that influence the intention to use a new technology and actual usage (Davis, 1989). TAM further states that perceived ease of use will influence the perceived usefulness because the easier a technology is to use; more useful it can be.

In order to examine the technology acceptance of VR simulators an initial investigation through an empirical experiment was conducted among the marine engineering students who currently have simulator training as part of their education. A total of 11 students (average age: 25.2, SD: 8.6) from the second-year marine engineering class at a University in Norway participated in the study on voluntary basis. All 11 were male participants and 3 of the participants had prior onboard experience (average: 1.33 years). 5 of the participants had previously heard about VR technology but none were familiar with the concept. All 11 participants had experience playing video games with their familiarity of video games ranging from moderate to extreme. The experimental task was to familiarize and learn to operate the fuel oil separator and Fresh water generator in the VR ship engine room simulator. Post the simulator task students were asked to fill a questionnaire to investigate the perceived usefulness and ease of use of the simulator. A seven-point Likert-like scale was developed with the following items based on TAM (Venkatesh, 2000),

1. Using the simulator improves my learning performance.
2. Using the simulator enhances my effectiveness in my learning.
3. I find the simulator to be useful in my education.
4. My interaction with the simulator is clear and understandable.
5. Interacting with the simulator does not require a lot of my mental effort.
6. I find the simulator to be easy to use.
7. I find it easy to get the simulator to do what I want it to do.

Questions 1 to 3 are concerned with perceived usefulness, 4 to 7 are concerned with perceived ease of use.

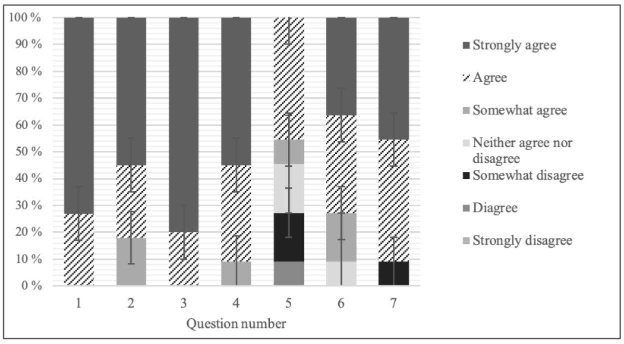

Figure 9: VR simulator Technology Acceptance among marine engineering students

Fig 9. shows the results from the empirical investigation. The result suggests that there is high perceived usefulness and ease of use among the students for VR simulators. Results from another study also indicate that VR increases the intrinsic motivation among the students (Mallam et al., 2019).

DISCUSSION

In this section, the potential of VR technology in MET and challenges from different aspects such as human factors, technology and organizational barriers is summarized and discussed. One critical aspect that is missing is the pedagogical aspect that concern about how students learn using the technology (Fowler, 2015). Results from the empirical study indicate that there is high user acceptance for VR among the students. It is also proven from previous studies that VR increase the motivation for learning. However, in order for fully utilizing these benefits, VR simulators have to be systematically integrated with the MET. The existing pedagogical models in MET need to be revisited and integration of VR technology should be carefully studied. The potential of VR technology in MET needs careful reflection to achieve actual educational efficacy. For example, the potential of VR includes decentralized, tailored for individuals and standardized assessment techniques and new feedback possibilities. But in order to utilize these to the fullest, one should fully understand the features and capabilities of VR.

The human factors issues of using VR is not neglectable. Some users experience physical discomfort using VR. Although the latest VR technology seems to have less/no effects on the users, latest research needs to confirm this. Although the discussed psychological effects are a fundamental issue with the technology itself, a guideline should be developed for sensible use of the technology within education and training. The other important human factors issue is the usability of VR. Once incorporated, the technology will be used by people in various age groups, gender and technology familiarity. With the different stakeholders and multidimensional nature of learning process combined with the complexity of VR technology, simulator developers and researchers should focus on the usability. It is important to develop and validate methods to quantify the quality of experience in VR, so that the impact of VR training applications on the users could be measured and better training experiences created.

From the technology perspective, the cost of technology is almost a non-issue now. However, developing VR content is still an expensive and time-consuming process, which could still affect the implementation of VR technology in MET.

From the organizational perspective, the resistance from within the organization should be clearly addressed. VR technology is not intended to fully replace the existing classroom-based learning and traditional simulators. But according to Dean et al., if implemented properly, VR could be a valuable supplement for teaching and learning resources and augment and reinforce the traditional methods (Dean et al., 2000).

CONCLUSION AND FUTURE WORK

This paper introduced the concept of VR technology based maritime training simulators, their applications, advantages and limitations. It aimed to contribute to the knowledge on safer and efficient adoptation of VR for maritime education and training. Initial results from our study also suggests that there is a high technology acceptance among marine engineering students for VR. This should be further investigated with more students and similar study should be conducted to measure the technology acceptance among other stakeholders in the maritime education. The flexibility and convenience of the advanced VR systems provide a wide range of new possibilities and applications for maritime training. In order to utilize the VR technology to its fullest potential, a constant dialogue must be held between the simulator instructors, developers, researchers and students to continually improve them. Further research is required to better understand the limitations of VR and how to overcome them, before implementing the technology in MET.

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REFERENCES

Berg, N., Storgård, J., and Lappalainen, J. 2013. The impact of ship crews on maritime safety. University of Turku, A, 64.

Berg, D., & Hauer, M. (2015). Digitalisation in shipping and logistics. *Asia Insurance Review, 52*.

BIMCO, I. (2015). Manpower Report-The global supply and demand for seafarers in 2015, Executive Summary.

Bloom, B. S. (1956). Taxonomy of educational objectives. Vol. 1: Cognitive domain. New York: McKay, 20-24.

Bowman, D. A., Koller, D., & Hodges, L. F. (1998). A methodology for the evaluation of travel techniques for immersive virtual environments. Virtual reality, 3(2), 120-131.

Burdea, G. C., & Coiffet, P. (2003). Virtual reality technology. John Wiley & Sons.

Buttussi, F., & Chittaro, L. (2018). Effects of Different Types of Virtual Reality Display on Presence and Learning in a Safety Training Scenario. *IEEE Trans Vis Comput Graph, 24*(2), 1063-1076. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/28092563. doi:10.1109/TVCG.2017.2653117

Carstens, A. and Beck, J. 2005. Get ready for the gamer generation. TechTrends, 49, 22–25.

2001. A taxonomy for learning, teaching and assessing: A revision of Bloom's taxonomy. New York. Longman Publishing. 2012.

Opriş, D., Pintea, S., García-Palacios, A., Botella, C., Szamosközi, Ş., & David, D. (2012). Virtual reality exposure therapy in anxiety disorders: a quantitative meta-analysis. *Depression and anxiety*, *29*(2), 85-93.

Calvert, S. L., & Tan, S. L. (1994). Impact of virtual reality on young adults' physiological arousal and aggressive thoughts: Interaction versus observation. *Journal of applied developmental psychology*, *15*(1), 125-139.

Chen, C. J. 2010. Theoretical bases for using virtual reality in education. Themes in Science Technology Education, 2, 71–90.

Davis, F. D. 1989. Perceived Usefulness, Perceived Ease of Use and User Acceptance of Information Technology. MIS Quarterly, 13, 319–340.

Dean, K. L., Asay-Davis, X. S., Finn, E. M., Foley, T., Friesner, J. A., Imai, Y., ... & Wilson, K. R. (2000). Virtual explorer: Interactive virtual environment for education. *Presence: Teleoperators & Virtual Environments*, *9*(6), 505-523.

Farra, S. L., Miller, E. T., and Hodgson, E. 2015. Virtual reality disaster training: translation to practice. Nurse Educ Pract, 15, 53–57.

Feiertag, J. and Berge, Z. L. 2008. Training Generation N: how educators should approach the Net Generation. Education+ Training, 50, 457–464.

Fowler, C. (2015). Virtual reality and learning: Where is the pedagogy? *British Journal of Educational Technology*, *46*(2), 412-422. doi:10.1111/bjet.12135

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education- state of the art and perspectives. *The 11th International Scientific Conference on eLearning and Software for Education Bucharest, 1*, 133-141.

Hauge, M. R., & Gentile, D. A. (2003, April). Video game addiction among adolescents: Associations with academic performance and aggression. In *Society for Research in Child Development Conference*.

Jr, J. J. L. 2000. A Discussion of Cybersickness in Virtual Environments. SIGCHI, 32, 47–56.

Kennerley, A. (2002). Writing the history of merchant seafarer education, training and welfare: Retrospect and prospect. Northern Mariner, 12(2), 1-22.

Logan, A. I. 1998. Training Beyond Reality. IFAC Proceedings Volumes. pages 31–33.

Mallam, S. C., Nazir, S., and Renganayagalu, S. K, Re- thinking Maritime Education, Training and Operations in the Digital Era: Applications for Emerging Immersive. WMU Journal of Maritime Affairs. Under review.

Mallam, S. C., et al., 2019. Design of Experiment Comparing Users of Virtual Reality Head-Mounted Displays and Desk- top Computers. Congress of the International Ergonomics Association, pages 240–249.

Mon-Williams, M., Warm, J. P., and Rushton, S. 1993. Binocular vision in a virtual world: visual deficits following the wearing of a head-mounted display. Journal of Ophthalmic Physiological Optics, 13, 387–391.

Nazir, S., Øvergård, K. I., and Yang, Z. 2015. Towards effective training for process and maritime industries, volume 3.

Nazir, S., et al., 2012. Virtual Reality and Augmented-Virtual Reality as Tools to Train Industrial Operators.

NIELSEN, J. (1993). Usability engineering. New York: Academic Press

Ortiz de Gortari, A. B., & Griffiths, M. D. (2014). Altered visual perception in Game Transfer Phenomena: An empirical self-report study. International Journal of Human-Computer Interaction, 30(2), 95-105.

Pantelidis, V. S. (1995). Reasons to use virtual reality in education. *VR in the Schools*, *1*(1), 9

Prensky, M. (2001). Digital natives, digital immigrants part 1. *On the horizon*, *9*(5), 1-6.

Psotka, J. 1995. Immersive training systems: Virtual reality and education and training. Journal of Instructional science, 23, 405–431.

Psotka, J. (2013). Educational games and virtual reality as disruptive technologies.

Renaud, K. J. 2015. Vestibular function and depersonalization/derealization symptoms. Multisensory research, 28, 637–651.

Rogers, E. 2003. Diffusion of Innovations (5th. Free Press, New York, NY.

Rolland, J. P., et al. 1995. Quantification of adaptation to virtual-eye location in see-thru head-mounted displays.

Salas, E., Bowers, C. A., and Rhodenizer, L. 1998. It Is Not How Much You Have but How You Use It:Toward a Rational Use of Simulation to SupportAviation Training. The International Journal of Aviation Psychology, 8, 197–208.

Salzman, M. C., Dede, C., Loftin, R. B., & Chen, J. (1999). A model for understanding how virtual reality aids complex conceptual learning. *Presence: Teleoperators & Virtual Environments*, *8*(3), 293-316.

Shen, J. and Eder, L. B. 2009. Intentions to use virtual worlds for education. Journal of Information Systems Education, 20, 225.

Stanney, K. M. and Kennedy, R. S. 1997. The Psychometrics of Cybersickness. Communications of ACM, 40, 67–68.

Turnbull, P. R. and Phillips, J. R. 2017. Ocular effects of virtual reality headset wear in young adults. Journal of Scientific reports, 7, 16172.

Stanney, K. M., Kennedy, R. S., & Drexler, J. M. (1997). *Cybersickness is not simulator sickness.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Stanney, K. M., Mourant, R. R., & Kennedy, R. S. (1998). Human Factors Issues in Virtual Environments- A Review of the Literature. Presence, 7(4), 327-351.

Sutherland, I. E. The ultimate display. *Multimedia: From Wagner to virtual reality*, 506-508.

Sutcliffe, A. G., & Kaur, K. D. (2000). Evaluating the usability of virtual reality user interfaces. Behaviour & Information Technology, 19(6), 415-426.

STCW, I. (2011). International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, (STCW) 1978, as amended in 1995/2010. I*nternational Maritime Organisation, London, UK.*

Sweeney, R. (2006). Millennial behaviors and demographics. Newark: New Jersey Institute of Technology, 12(3), 10.

Velev, D., & Zlateva, P. (2017). Virtual reality challenges in education and training. *International Journal of Learning and Teaching*, *3*(1), 33-37.

Venkatesh, V. 2000. Determinants of perceived ease of use: Integrating control, intrinsic motivation, and emotion into the technology acceptance model. Information systems research, 11, 342–365.

Wharton, C., Reiman, J., Levis, C. & Polson, P. (1994). The cognitive walkthrough method: a practitioner's guide. In J. Nielsen & R.L. Mack (Eds) Usability inspection methods, (pp. 105-140). New York: J Wiley.

Catching up with time? Examining the STCW competence framework for autonomous shipping

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Abstract – **The increased automation and digitalization in maritime industry has gradually changed the operational environment of ships and the competences required for seafarers. In the era of autonomy, these developments may dramatically restructure the work processes and require new competences to be acquired by the personnel involved in ship operations. The aim of this study is to explore the suitability of the existing STCW competence framework for Officers in Charge of a Navigational Watch (OICNW) under autonomy degree two as defined by IMO. A total number of n=82 OICNWs participated in a survey designed to evaluate the applicability of 66 Knowledge, Understanding and Proficiency items (KUPs) as listed in STCW Table A-II/1. An Exploratory Factor Analysis resulted in emergence of 9 factors that indicated the relevant competence themes for autonomy degree two operations. The findings are discussed with possible implications towards the training of future OICNW.**

***Keywords*:** Future competencies, STCW, Maritime Autonomous Surface Ships, Autonomy level, MASS

INTRODUCTION

Maritime industry is undergoing radical changes with the ongoing introduction of automation and digitalization (Kitada et al., 2018). Modern ships have bigger dimensions and more advanced support systems, though being manned by fewer specialized crew members than their predecessors. Introduction of autonomous ships is expected to be the next major technological step-change in shipping. The arguments in support of introducing autonomous ships range from economic reasons through increased efficiency to safety considerations (Brandsæter & Knutsen, 2018). They might also result in new modes of ship transportation than present. The era of autonomy, therefore could dramatically restructure the work processes and require new competences to be acquired by the personnel involved in the ship operations (Relling, Lützhöft, Ostnes, & Hildre, 2018).

The International Maritime Organization (IMO) is the global maritime authority for establishing the standards for safety, security and environmental performance of international shipping. To cope with the increasing industrial demands and accelerated technological development, IMO during its MSC 98th initiated a regulatory scoping exercise for the use of Maritime Autonomous Surface Ships (MASS). The intention of this scoping exercise is to consider human element, legal aspect and environmental concerns for the autonomous ships (IMO, 2017). In the context of autonomous ships, the skills and competences that are required for the officers in charge of a navigational watch is relatively unknown territory. There is a need for detailed investigation of the needed competencies in order to correspondingly address the novel training requirements of future OICNW. The Standards of Training, Certification & Watchkeeping convention (STCW 1978 as amended) – as one of the key instruments of IMO in regulating the minimum qualification for seafarers worldwide – provides the global benchmark for training of seafarers. It establishes the internationally accepted qualification standards for officers and ratings serving onboard merchant ships. In this paper, the suitability of the present competence framework as defined by STCW was investigated for autonomy degree two operations. The scope was narrowed down to the competence requirements for navigation officers in the operational level as defined in the STCW code, Part A, Chapter 2, Table A-II/1 (IMO, 2011).

Autonomy framework for maritime domain

In order to test the suitability of STCW regulations, it is important to clarify first the degrees of autonomy. Different organizations have proposed several definitions for autonomous shipping. In this paper, we aimed to use the MASS definitions as proposed during IMO MSC 100th session in 2018 (IMO, 2018)

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due to international profile of the respondents. According to this framework as illustrated in Figure 1, there are four degrees of autonomy wherein the first and the second degree, human operators are still present onboard the ship. OICNW remain onboard to maneuverer and control the shipboard systems in Degree one. Although some systems can be automated, but the control of the ship is performed onboard. However, in Degree two the ship is controlled from a remote location. The OICNW are available onboard to take control of the system if necessary. In Degree three, the ship is remotely controlled without any OICNW onboard. Whereas the Degree four, which refers to the ship that is completely autonomous in which the ship is able to determine the decisions and the actions by itself. Degree three and four, which has no human presence on ship is difficult to be realized in practice in near future due to liability issues (Wróbel, Montewka, & Kujala, 2017). In addition, according to article 3 (Application) of the STCW Convention, it is stipulated that the convention only applies to ships with seafarers on board. The regulatory scoping exercise on Maritime Autonomous Surface Ships (MASS) executed by the IMO Maritime Safety Committee for STCW is currently focusing on autonomy degree two (IMO, 2019). Accordingly, it is more reasonable to evaluate the suitability of STCW regulations under autonomy degree two operations.

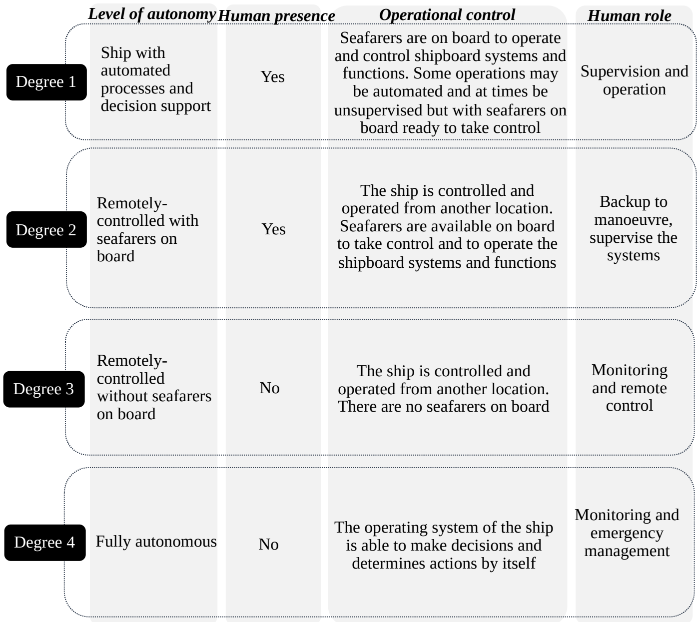

Figure 1. Four degrees of autonomy as defined by IMO (Adapted from Kim, Sharma, Gausdal, & Chae, 2019)

STCW regulations and codes for seafarer competence

Safety and efficiency of ship operations, protection of the marine environment and life at sea depends largely upon competent crew. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, 2011) was the first international convention to establish the minimum standards for navigational officers worldwide. This convention was introduced in the year 1978 and entered into force in 1984. It sets minimum qualification standards for masters, officers and watch personnel on seagoing merchant ships. The convention, after its establishment was revised in 1995 to include Competency Based Training which required concrete outcomes and a set of Knowledge, Understanding and Proficiency (KUPs) items that the qualified officers in charge of a navigational watch should demonstrate (Emad & Roth, 2008). The convention was further amended in 2010 and outlined new definitions for Electro-Technical Officers (ETO) and new training requirements with respect to use of ECDIS and also requiring training in leadership and teamwork, security-related familiarization, security-awareness training etc. In the era of autonomous operations, many of the routine operations are more likely to be automated (Porathe, 2019), and therefore it will be necessary to revise the competence requirements. The current version of STCW 1978 (as amended) has 19 competence themes consisting of 66 Knowledge, Understanding & Proficiency items (KUPs), which specifies the minimum standard of competence for officers in charge of a navigational watch on ships of 500 gross tonnage or more (IMO, 2011).

METHOD

The aforementioned 66 STCW Table A-II/1 KUPs have been used in a survey questionnaire, where respondents were asked to rate the suitability of each KUPs for degree two autonomous operations on a Likert scale from 1 (Extremely important) to 5 (Not at all important). The KUPs were not modified rather, the original text from STCW was followed in order to maintain the originality of the codes. The questionnaire was digitalized using platform Qualtrics™. The questionnaire was designed using "forced responses" function for the listed KUPs, so that there are no missing values and the respondents had to complete all the answers before proceeding further. Only completed responses will be recorded and reported to the researchers. Several demographic questions were also included at the end of the questionnaire to facilitate the understanding of survey responses. The questionnaire was then sent out to OICNW working on international merchant shipping industry through purposive non-random sampling approach using professional contacts. The survey data was collected from March to April 2019 period. A total number of 82 valid responses were registered out of 114 respondents (Response rate – 71.9%). The survey utilized an anonymous link with no personal information being collected. The majority of respondents were from the tanker sector. The demographics data was collected for all the respondents (except 2 cases of missing values) and the information is summarized in Table 1.

Table 1. Demographic characteristics of the respondents

Range		Frequency	Percent
Industrial area	Shipping company	64	80.0
	Others	4	5.0
	Shipping management company	11	13.7
	Maritime training institute/provider	1	1.3
Shipping sectors	Wet Bulk (Tanker sector)	51	63.7
	Dry Bulk	5	6.3
	Cargo Liners and Container Ships	18	22.4
	Passenger Liners/Cruise Ships/Ferries	3	3.8
	Other shipping sectors	3	3.8
Year of experience	0-5 years	57	71.3
	6-10	9	11.2
	11-15	3	3.8
	+ 15 years	11	13.7

To ensure the respondents have a sufficient understanding regarding the definition of autonomy degree two, the questionnaire begins with an introduction of the autonomy framework by IMO. The analysis of data gathered was performed using the software SPSS^{TM} version 25. The responses derived were then analysed using an Exploratory Factor Analysis (EFA). EFA is a multivariate statistical technique to reduce the large number of variables into smaller set of factors that represent the sets of co-related variables (Kilner, 2004; Tabachnick & Fidell, 1984). EFA allows the researchers to undertake parsimonious analysis, generate theory and also evaluate the construct validity of the measurement instrument (Williams, Onsman, & Brown, 2010). There are various guidelines available in the literature regarding the sample size for EFA. While some of the literature suggest a sample to variable ratio of 3:1, 4:1 or as large as 15:1 & 20:1, there are no absolute guidelines. In this regard, obviously the more the sample size is, the better conclusions can be drawn from the data. However, Bryman (1997) argued that at least a sample size equal or greater as the number of items in the measurement instrument should be present, which was possible in this study. The result, derived from the data analysis, is presented in the following section.

RESULTS

A Principal Component Analysis (PCA) was conducted on the 66 questionnaire items with varimax rotation. The Bartlett's test of sphericity was significant ($p<0.001$). KMO value signifying the measure of sampling adequacy was greater than 0.5. The descriptive statistics table is provided in Table 2. It also illustrates the 19 competences as described in Table A-II/1, as well as the range of KUPs i.e. the sequential order in which they cluster to form a specific competence.

Table 2. Descriptive statistics for all KUPs in Table A-II/1

	M	SD
Competence 1: Plan and conduct a passage and determine position		
KUP 1 Ability to determine the ship's position by use of celestial bodies	2.22	1.043
KUP 2 Ability to determine the ship's position by use of 1) landmarks, 2) aids to navigation, including lighthouses, beacons and buoys, 3) dead reckoning, taking into account winds, tides, currents and estimated speed	2.07	.979
KUP 3 Have thorough knowledge of and ability to use nautical charts, and publications, such as sailing directions, tide tables, notices to mariners, radio navigational warnings and ships' routeing information	2.06	.947
KUP 4 Ability to determine the ship's position by use of electronic navigational aids	1.65	.692
KUP 5 Ability to operate the equipment and apply the information correctly	1.77	.742
KUP 6 Have knowledge of the principles of magnetic and gyro-compasses	1.98	.846
KUP 7 Ability to determine errors of the magnetic and gyro-compasses, using celestial and terrestrial means, and to allow for such errors	2.39	1.141
KUP 8 Have knowledge of steering control systems, operational procedures and change-over from manual to automatic control and vice versa. Adjustment of controls for optimum performance	1.91	.864
KUP 9 Ability to use and interpret information obtained from shipborne meteorological instruments	2.50	.892
KUP 10 Have knowledge of the characteristics of the various weather systems, reporting procedures and recording systems	2.22	.956
KUP 11 Ability to apply the meteorological information available	2.34	.864
Competence 2: Maintain a safe navigational watch		
KUP 12 Have thorough knowledge of the content, application and intent of the International Regulations for Preventing Collisions at Sea, 1972, as amended	1.82	.818
KUP 13 Have thorough knowledge of the Principles to be observed in keeping a navigational watch	2.16	1.000
KUP 14 Proficient in use of routeing in accordance with the General Provisions on ships' routeing	2.38	.884
KUP 15 Proficient in use of information from navigational equipment for maintaining a safe navigational watch	1.90	.826
KUP 16 Have knowledge of blind pilotage techniques	2.39	.940
KUP 17 Proficient in use of reporting in accordance with the General Principles for Ship Reporting Systems and with VTS procedures	2.21	.885
KUP 18 Knowledge of bridge resource management principles, including 1) allocation, assignment, and prioritization of resources, 2) effective communication 3) assertiveness and leadership, 4) obtaining and maintaining situational awareness, 5) consideration of team experience	2.17	1.004
Competence 3: Use of radar and ARPA to maintain safety of navigation		
KUP 19 Have knowledge of the fundamentals of radar and automatic radar plotting aids (ARPA)	1.99	.762
KUP 20 Ability to operate and to interpret and analyse information obtained from radar and ARPA performance, including 1) factors affecting performance and accuracy, 2) setting up and maintaining displays, 3) detection of misrepresentation of information, false echoes, sea return, etc., racons and SARTs	1.88	.744

KUP 21 Ability to operate and to interpret and analyse information obtained from radar and ARPA use, including 1) range and bearing; course and speed of other ships; time and distance of closest approach of crossing, meeting overtaking ships, 2) identification of critical echoes; detecting course and speed changes of other ships; effect of changes in own ship's course or speed or both, 3) application of the International Regulations for Preventing Collisions at Sea, 1972, as amended, 4) plotting techniques and relative- and true-motion concepts, 5) parallel indexing	1.91	.789
KUP 22 Awareness of principal types of ARPA, their display characteristics, performance standards and the dangers of over-reliance on ARPA	2.12	.760
KUP 23 Ability to operate and to interpret and analyse information obtained from ARPA, including 1) system performance and accuracy, tracking capabilities and limitations, and processing delays, 2) use of operational warnings and system tests, 3) methods of target acquisition and their limitations, 4) true and relative vectors, graphic representation of target information and danger areas, 5) deriving and analysing information, critical echoes, exclusion areas and trial manoeuvres	1.94	.759
Competence 4: Use of ECDIS to maintain the safety of navigation		
KUP 24 Have knowledge of the capability and limitations of ECDIS operations, including 1) a thorough understanding of Electronic Navigational Chart (ENC) data, data accuracy, presentation rules, display options and other chart data formats, 2) the dangers of over-reliance, 3) familiarity with the functions of ECDIS required by performance standards in force	1.76	.779
KUP 25 Proficient in operation, interpretation, and analysis of information obtained from ECDIS, including 1) use of functions that are integrated with other navigation systems in various installations, including proper functioning and adjustment to desired settings, 2) safe monitoring and adjustment of information, including own position, sea area display, mode and orientation, chart data displayed, route monitoring, user-created information layers, contacts (when interfaced with AIS and/or radar tracking) and radar overlay functions (when interfaced), 3) confirmation of vessel position by alternative means, 4) efficient use of settings to ensure conformance to operational procedures, including alarm parameters for anti-grounding, proximity to contacts and special areas, completeness of chart data and chart update status, and backup arrangements, 5) adjustment of settings and values to suit the present conditions	1.80	.793
Competence 5: Respond to emergencies		
KUP 26 Ability to take precautions for the protection and safety of passengers in emergency situations	1.46	.632
KUP 27 Ability to take initial actions following a collision or a grounding; and ability to assess initial damage and perform control	1.40	.626
KUP 28 Appreciate the procedures to be followed for rescuing persons from the sea, assisting a ship in distress, responding to emergencies which arise in port	1.54	.706
Competence 6: Respond to a distress signal at sea		
KUP 29 Have knowledge of the contents of the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual	1.84	.853
Competence 7: Use the IMO Standard Marine Communication Phrases and use English in written and Oral form		
KUP 30 Have adequate knowledge of the English language to enable the officer to use charts and other nautical publications, to understand meteorological information and messages concerning ship's safety and operation, to communicate with other ships, coast stations and VTS centres and to perform the officer's duties also with a multilingual crew, including the ability to use and understand the IMO Standard Marine Communication Phrases (IMO SMCP)	1.71	.762
Competence 8: Transmit and receive information by visual signalling		
KUP 31 Ability to use the International Code of Signals	2.04	.949
KUP 32 Ability to transmit and receive, by Morse light, distress signal SOS as specified in Annex IV of the International Regulations for Preventing Collisions at Sea, 1972, as amended, and appendix 1 of the International Code of Signals, and visual signalling of single-letter signals as also specified in the International Code of Signals	2.23	1.169
Competence 9: Manoeuvre the ship		
KUP 33 Have knowledge of ship manoeuvring and handling, including knowledge of 1) the effects of deadweight, draught, trim, speed and under-keel clearance on turning circles and stopping distances, 2) the effects of wind and current on ship handling, 3) manoeuvres and procedures for the rescue of person overboard, 4) squat, shallow-water and similar effects, 5) proper procedures for anchoring and mooring	2.09	.905
Competence 10: Monitor the loading, stowage, securing, care during the voyage and the unloading of cargoes		
KUP 34 Have knowledge of the effect of cargo, including heavy lifts, on the seaworthiness and stability of the ship	2.02	.981
KUP 35 Have knowledge of safe handling, stowage and securing of cargoes, including dangerous, hazardous and harmful cargoes, and their effect on the safety of life and of the ship	1.76	.840
KUP 36 Ability to establish and maintain effective communications during loading and unloading	2.10	1.001
Competence 11: Inspect and report defects and damage to cargo spaces, hatch covers and ballast tanks		
KUP 37 Have knowledge and ability to explain where to look for damage and defects most commonly encountered due to 1) loading and unloading operations, 2) corrosion, 3) severe weather conditions	1.93	.886
KUP 38 Ability to state which parts of the ship shall be inspected each time in order to cover all parts within a given period of time	2.27	.802
KUP 39 Ability to identify those elements of the ship structure which are critical to the safety of the ship	1.91	.773
KUP 40 Ability to state the causes of corrosion in cargo spaces and ballast tanks and how corrosion can be identified and prevented	1.98	.875
KUP 41 Have knowledge of procedures on how the inspections shall be carried out	2.20	.999
KUP 42 Ability to explain how to ensure reliable detection of defects and damages	1.99	.778
KUP 43 Have understanding of the purpose of the "enhanced survey programme"	2.45	.996
Competence 12: Ensure compliance with pollution prevention requirements		
KUP 44 Have knowledge of the precautions to be taken to prevent pollution of the marine environment	1.68	.887
KUP 45 Awareness of anti-pollution procedures and all associated equipment	1.91	.892
KUP 46 Awareness of importance of proactive measures to protect the marine environment	1.84	.923
Competence 13: Maintain seaworthiness of the ship		
KUP 47 Have working knowledge and application of stability, trim and stress tables, diagrams and stress-calculating equipment	2.10	.883
KUP 48 Have understanding of fundamental actions to be taken in the event of partial loss of intact buoyancy	2.27	.917
KUP 49 Have understanding of the fundamentals of watertight integrity	2.24	.910
KUP 50 Have general knowledge of the principal structural members of a ship and the proper names for the various parts	2.30	.965
Competence 14: Prevent, control and fight fires onboard		
KUP 51 Ability to organize fire drills	1.85	.970
KUP 52 Have knowledge of classes and chemistry of fire	1.85	.970
KUP 53 Have knowledge of fire-fighting systems	1.66	.773
KUP 54 Have knowledge of action to be taken in the event of fire, including fires involving oil systems	1.71	.824

Competence 15: Operate life-saving appliances		
KUP 55 Ability to organize abandon ship drills and knowledge of the operation of survival craft and rescue boats, their launching appliances and arrangements, and their equipment, including radio life-saving appliances, satellite EPIRBs, SARTs, immersion suits and thermal protective aids	1.76	.869
Competence 16: Apply medical first onboard ship		
KUP 56 Awareness of the practical application of medical guides and advice by radio, including the ability to take effective action based on such knowledge in the case of accidents or illnesses that are likely to occur on board ship	1.96	.793
Competence 17: Monitor compliance with legislative requirements		
KUP 57 Have basic working knowledge of the relevant IMO conventions concerning safety of life at sea, security and protection of the marine environment	1.96	.867
Competence 18: Application of leadership and teamworking skills		
KUP 58 Have working knowledge of shipboard personnel management and training	2.34	.919
KUP 59 Have knowledge of related international maritime conventions and recommendations, and national legislation	2.09	.919
KUP 60 Ability to apply task and workload management, including 1) planning and co-ordination, 2) personnel assignment, 3) time and resource constraints, 4) prioritization	2.44	.876
KUP 61 Have knowledge and ability to apply effective resource management, including 1) allocation, assignment, and prioritization of resources, 2) effective communication onboard and ashore, 3) decisions reflect consideration of team experiences, 4) assertiveness and leadership, including motivation, 5) obtaining and maintaining situational awareness	2.24	.924
KUP 62 Have knowledge and ability to apply decision-making techniques, including 1) situation and risk assessment, 2) identify and consider generated options, 3) selecting course of action, 4) evaluation of outcome effectiveness	2.12	.852
Competence 19: Contribute to the safety of personnel and ship		
KUP 63 Have knowledge of personal survival techniques	1.70	.781
KUP 64 Have knowledge of fire prevention and ability to fight and extinguish fires	1.61	.662
KUP 65 Have knowledge of elementary first aid	1.74	.814
KUP 66 Have knowledge of personal safety and social responsibilities	1.68	.718

The authors examined the factor loading of all the KUPs and removed the KUPs that did not load on any of the major components, with a score of more than 0.4. An initial analysis was run to obtain the eigenvalues greater than 1 for the components in the data. 18 components (factors) had eigenvalues over 1 and together explained 77.2% of the variance. However, there were 9 components that were having loading from only single item and therefore were not retained as factors. The remaining factors that were extracted composed of at least 2 items. The combination explained 58.2% of the variance present in the data. Table 3 shows the factor loading after rotation.

Out of the 9 factors extracted in the analysis, factors 1, 2, 3, 5, & 6 represented existing competence themes as presented in Table 1. However, the factors 4, 7, 8 & 9 did not include all the KUPs from specific competence themes and therefore were assigned new labels. Factor 1 represents the KUPs from 51-54 that have perfectly overlapped with the competence 14 outlined in Table A-II/1. Thus, this factor retains the original name as "*Prevent, control and fight fires onboard*", which indicated that this competence theme would still be relevant under autonomy level two operation.

Table 3. Rotated component matrix for the extracted factors

	Component								
	1	2	3	4	5	6	7	8	9
KUP 53	.840								
KUP 52	.804								
KUP 54	.787								
KUP 51	.658								
KUP 20		.782							
KUP 19		.745							
KUP 22		.705							
KUP 61			.848						
KUP 60			.718						
KUP 58			.677						
KUP 62			.630						
KUP 15				.706					
KUP 6				.671					
KUP 13				.635					
KUP 25				.616					
KUP 63					.751				
KUP 66					.705				
KUP 65					.691				
KUP 64					.611				
KUP 44						.822			
KUP 46						.820			
KUP 45						.782			
KUP 35							.743		
KUP 28							.612		
KUP 2								.827	
KUP 1								.804	
KUP 17									.800
KUP 31									.760

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 59 iterations.

Factor 2 represents the KUP 19, 20 and 22. It also largely represented the competence 3 "*Use of radar and ARPA to maintain the safety of navigation*". The KUP 23 was dropped due to low factor loading (<0.4). Having the abilities to analyze and interpret information obtained from radar and ARPA is still being considered as a dominant competence. KUP 58, 60, 61 and 62 falls under competence 18 "*Application of leadership and teamworking skills*". KUP 59 was excluded due to low factor loading (<0.4). Factor 4 included KUP 6, 13, 15, 25, which was assigned a new label as "*Watchkeeping with the aid of navigational equipment*". Factor 5 included KUP 63, 64, 65 and 66, which perfectly corresponded to competence 19 of STCW Table A-II/1 and therefore the original label "*Contribute to the safety of ship and the personnel*" was kept. Factor 6 contained KUP 44, 45 and 46 which perfectly overlapped with competence 12 titled "*Ensure compliance with pollution prevention requirements*". Factor 7 had KUPs 28 and 35. These 2 KUP were – "*Appreciate the procedures to be followed for rescuing persons from the sea, assisting a ship in distress, responding to emergencies which arise in port*" and "*Have knowledge of safe handling, stowage and securing of cargoes, including dangerous, hazardous and harmful cargoes, and their effect on the safety of life and of the ship*". We labelled this factor as "*Abilities to respond in emergencies and cargo management skills*". Factor 8 included the KUPs 1 and 2 which were labelled as competences "*Celestial & Terrestrial navigation skills*" on the account it constitutes KUPs 1 and 2. Finally, the factor 9 was labelled as "*Maintain safe navigation based on understanding of visual signal*".

A reliability analysis of the extracted factors was performed resulting in the following scores for each factor as illustrated in the Table 4 below.

Table 4. Reliability measures of the extracted factors

Component	No. of items	Cronbach' s α
1	4	0.852
2	3	0.819
3	4	0.810
4	4	0.759
5	4	0.792
6	3	0.852
7	2	0.555
8	2	0.769
9	2	0.657

DISCUSSION

The 66 KUPs of the Table A-II/1 were rated on a Likert scale from 1 (Extremely important) to 5 (Not at all important). The most relevant KUP score was achieved by the KUP no. 27 "*Ability to take initial actions following a collision or grounding; and ability to assess initial damage and perform control*", followed by no. 26 "*Ability to take precautions for the safety of passengers in emergency situations*". This highlights the relative importance placed by the respondents on emergency management procedures in the autonomy degree two operations. The least relevant KUP score was achieved by no. 9 "*The ability to use and interpret the information obtained from shipborne meteorological instrument*", followed by no. 43 "*Have understanding of the purpose of the "enhanced survey programme*". The new set of competences derived through EFA are illustrated in Table 5 below.

Table 5. Competences derived through EFA for navigation officers for Degree 2 autonomous operations

No.	Competences
1	Prevent, control and fight fires onboard
2	Use of radar and ARPA to maintain the safety of navigation
3	Application of leadership and teamworking skills
4	Watchkeeping with the aid of navigational equipment
5	Contribute to the safety of ship and the personnel
6	Ensure compliance with pollution prevention requirements
7	Abilities to respond in emergencies & cargo management skills
8	Celestial & Terrestrial navigation skills
9	Maintain safe navigation based on understanding of visual signal

The results demonstrate that only some of the KUPs were rated relevant by the respondents, which implies that with the altered work characteristics with increased automation in Degree two autonomous operations may mean that some of the present KUPs required by the navigators will become obsolete and require new and more specific competence themes to be acquired. Appropriate re-skilling of the navigators will therefore be required to adequately cater to new operational demands.

Safety and efficiency of ship operations, protection of the marine environment and life at sea largely depends upon competent crews. This study was a step towards investigating the suitability of present STCW 1978 framework for the future competencies of the OICNW. The aim was to examine the relevance of competences and evaluate the individual KUP items to contribute in the discussion with respect to training and education of future navigators. However, several limitations of the study need to be mentioned. First of all, comprehensive understanding regarding the technical aspect of autonomous shipping should be prerequisite when considering the future competencies of the navigators. Future studies should explore the technological advancements jointly with the required competences. Secondly, the majority of the respondents had relatively less experience in merchant shipping industry. Thirdly, the method utilized i.e. EFA has also certain inherent limitations. The KMO measure was relatively low, indicating the need for larger sample size. Future studies should be directed in collection of more samples to ensure better generalizability of the results and in examining the suitability of other competence requirements stipulated in STCW 1978 as amended (e.g. Table A-II/2), as well as for roles within other departments in merchant shipping sector such as marine engineer officers. Such investigation carried out by different stakeholders could aid the revision and integration of changes that will be required for the STCW regulations to prepare competent seafarers for the dynamically evolving nature of autonomous shipping. This research aims to pave the way for academic community to delve deeper in to understanding the requirement of competence for seafarers to achieve appropriate training solutions.

CONCLUSION

Maritime industry is undergoing radical changes with the technological advancement and fast introduction of automation technologies. To cope with increasing industrial demand and accelerated technological development, the global standard of maritime training and certification will also require revision and adaption. This paper had initiated a preliminary exploration regarding the suitability of existing STCW framework for the OICNW under the MASS autonomy degree two. The results have highlighted that several competences remain significant for future OICNW. However, some competences reviewed to come across as less important when some functions are taken over by automation technologies. Future research directions should look more closely into the necessary competences for the OICNW across different levels of autonomy and ensure that future OICNW are equipped with sufficient levels of competence to excel in the era of autonomous shipping.

REFERENCES

Brandsæter, A., & Knutsen, K. (2018). Towards a framework for assurance of autonomous navigation systems in the maritime industry. In *Safety and Reliability–Safe Societies in a Changing World* (pp. 449-457): CRC Press.

Bryman, A., Cramer,D. (1997). *Quantitative data analysis with SPSS for Windows: A guide for social scientists*: London: Routledge.

Emad, G., & Roth, W. M. (2008). Contradictions in the practices of training for and assessment of competency: A case study from the maritime domain. *Education+ Training, 50*(3), 260-272.

IMO. (2011). International Convention on Standards of Training, Certification and Watchkeeping for Seafarers,(STCW) 1978, as amended in 1995/2010. International Maritime Organisation, London, UK.

IMO. (2017). MSC 98th session (2017).

IMO. (2018). Working group report in 100th session of IMO Maritime Safety Committee for the regulatory scoping exercise for the use of maritime autonomous surface ships (MASS). Maritime Safety Committee, 100th session.

IMO. (2019). GISIS: Regulatory scoping exercise on Maritime Autonomous Surface Ships (MASS): https://gisis.imo.org/Members/MASS/Regulations.aspx?id=4548.

Kilner, T. (2004). Educating the ambulance technician, paramedic, and clinical supervisor: using factor analysis to inform the curriculum. *Emergency Medicine Journal, 21*(3), 379-385.

Kim, T.-e., Sharma, A., Gausdal, A. H., & Chae, C.-j. (2019). Impact of autonomy on gender parity in maritime industry (Accepted). *WMU Journal of Maritime Affairs*.

Kitada, M., Baldauf, M., Mannov, A., Svendsen, P. A., Baumler, R., Schröder-Hinrichs, J.-U., . . . Lagdami, K. (2018). *Command of Vessels in the Era of Digitalization.* Paper presented at the International Conference on Applied Human Factors and Ergonomics.

Porathe, T. (2019). *Interaction Between Manned and Autonomous Ships: Automation Transparency*. In *Proceedings of the 1st International Conference on Maritime Autonomous Surface Ships*. SINTEF Academic Press.

Relling, T., Lützhöft, M., Ostnes, R., & Hildre, H. P. (2018). *A Human Perspective on Maritime Autonomy*. Paper presented at the International Conference on Augmented Cognition.

Tabachnick, B. G., & Fidell, L. S. (1984). Using Multivariate Statistics. *Applied Psychological Measurement*, *8*(4), 471-471. :Doi 10.1177/014662168400800412

Williams, B., Onsman, A., & Brown, T. (2010). Exploratory factor analysis: A five-step guide for novices. *Australasian Journal of Paramedicine, 8*(3). 1-13.

Wróbel, K., Montewka, J., & Kujala, P. (2017). Towards the assessment of potential impact of unmanned vessels on maritime transportation safety. *Reliability Engineering & System Safety, 165*, 155-169.

Kongsberg Simulator used in Advanced Firefighting Training

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Personnel onboard a ship must be able to handle critical incidents while the ship is at sea. Traditional training methods can be complex, costly and time consuming, placing pressure on both company and crew. However, this can be negated using simulation training. The STCW Table A-VI/3 states a minimum standard of competence in advanced firefighting training. The methods for demonstrating the competence are done by practical exercises and instruction conducted under approved and truly realistic training conditions e.g in simulated shipboard conditions. The K-Sim Safety simulator is developed as a tool to increase the realism in advanced firefighting training. The simulator allows incident command and emergency response training; the simulator users can experience an incident as if it happened in real-life. During an exercise, they can assess the situation and determine the best response strategy, implement it and then observe the consequences of their decisions during a debrief afterwards.

Keywords
Advanced firefighting simulator, management training, decision making in safety situations, virtual reality.

INTRODUCTION

Kongsberg has a long history and developed simulators used for maritime training for over 40 years. The entire simulator product portfolio consists of engine room, navigation, cargo handling, ballast handling, crane and offshore simulators. The simulators are very flexible and can be configured on a PC desktop up to an operational full mission simulator using customized panels and ship equipment. In recent years many of the simulators have 3D displays of vital parts and a selection of the K-Sim Engine models have 3D virtual walkthrough systems available.

We have now used our experience and technology to increase the training possibilities and safety to sea even more. We are launching a new type of simulator to be used in advanced firefighting training, called K-Sim Safety.

K-SIM SAFETY

The simulator has been designed and manufactured in full observance of the STCW (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers) firefighting/search & rescue competence requirements as expressed in regulation VI/3, section A-VI/3 table A-VI/3-1.

The STCW Table A-VI/3 states a minimum standard of competence in advanced firefighting:

- Control firefighting operations aboard ships
- Organize and train fire parties
- Inspect and service fire-detection and fire-extinguishing systems and equipment
- Investigate and compile reports on incidents involving fire

Based on the STCW requirements for training, DNV GL released a new Standard for Certification of Maritime Simulators (DNVGL-ST-0033) in May 2019. The two competencies addressed by the DNV GL standard are:

- Control firefighting aboard ships (Table A-VI/3.1)
- Organize and train fire parties (Table A-VI/3.2).

K-Sim Safety received the Statement of Compliance for Simulator Class A in June 2019. A Class A simulator is a full mission simulator capable of simulating a ship bridge or safety command centre, accommodation and machinery spaces where the physical configuration with multiple station require learners to operate in a virtual environment. The management and the fire teams will operate from dedicated locations and external radio communication is used between the different teams. For the last two competencies in the STCW table, the advanced firefighting training must be performed with real firefighting equipment.

The main training elements in K-Sim Safety simulator:

- Management training
- Communication
- Compare general arrangement drawings with real life
- Familiarization with emergency exits
- Location of fire
- Location of firefighting equipment
- Finding missing persons
- Blackout training
- Flooding
- Evacuation
- Assessment of actions and decisions

The K-Sim Safety contains a 3D virtual environment based on real general arrangement data from a 152.000 dwt hull Suezmax Crude Oil Carrier with 7 decks. Crew from different types of ship are often attending advanced firefighting courses together at the training centers. But the learning objectives are pretty much accomplished regardless of the type of ship they come from when using this simulator. The possible scenarios in the simulator can make good discussions based on experiences from real life.

The advanced firefighting simulator can be integrated with K-Sim Engine, K-Sim Cargo and the corresponding K-Sim Navigation simulator for total ship training for a crude oil carrier.

FULL MISSION CONCEPT

The K-Sim Safety solution includes a full mission simulator, which can train up to three different teams at the same time; one management team and two firefighting teams.

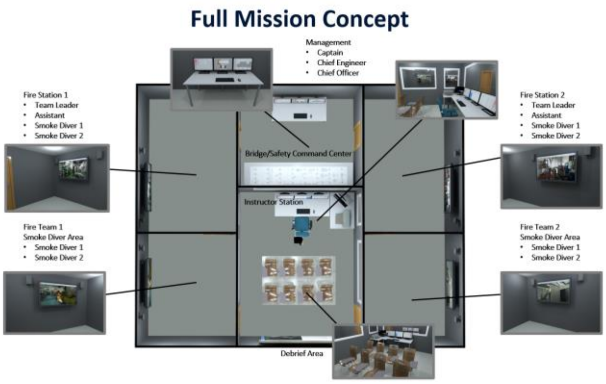

Figure 1. K-Sim Safety Full Mission Concept

The full mission system includes two separate fire team muster stations (fire station 1 and 2) comprising an interactive walkthrough virtual environment of the entire engine room and four upper decks including hotel area.

The simulator features detailed of visual models such as equipment for the fire teams, doors, fire doors, lights, fire, smoke and people. Corridors, stairs, cabins, offices, lockers, storages, emergency exits and muster stations including firefighting and lifesaving devices are all available in the 3D environment, based on the general arrangement of the simulated ship.

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Simulated visual effects in 3D environment:

- Fire
- Smoke
- Flooding
- Electrical lighting control (normal, emergency light, blackout)
- Ventilation control panel
- Missing persons (victims)
- Fire team presence
- Smoke diver outfit
- Fire extinguisher equipment

In an emergency, the management team (often consisting of the Captain, the Chief Engineer and the Chief Officer) will meet at the bridge/safety command centre. Their main task is to manage the firefighting by communication to the other internal teams as well as external communication using radio.

During an exercise, each fire team may consist of a team leader, an assistant and two smoke divers who can train on procedures and virtually walk around selected areas of the ship. K-Sim Safety facilitates training on emergency communication, the use of extinguisher equipment and search for missing persons. Training of communication between the teams is also extremely important, since communication error is one of the main causes of fatal accidents.

A x-box controller is used for navigating around the virtual ship. When a situation requires the smoke divers to split from their managers, they can continue into the virtual smoke diver's area with their own monitor and x-box controller located in another room.

Bridge/Safety Command Centre

The bridge/safety command centre is equipped with an Integrated Automation System (IAS) and safety panels giving an overview of the emergency, supporting the management team to take critical decisions.

Systems available from the bridge/safety command centre:

- Integrated Automation System
- Fire Detection System
- Water Mist System
- Fire Pumps
- Emergency Shut-off Panel
- CO^2 System
- Fire Door Panel
- CCTV System
- Fire Control and Safety Plan

K-Sim Safety includes a fire control and safety plan for the simulated ship. This plan is a mandatory requirement of the SOLAS convention onboard ships. The plan is located at selected locations on the ship and provides detailed information about fire stations, type of fire detection and firefighting systems available onboard.

The fire door panel can be operated from the bridge/safety command centre. All fire doors can be remotely closed from this panel and it is possible to block the doors in open position both by the instructor and the fire team members in the virtual world. The fire team members must check the fire doors and close them in a fire situation.

The Fire Station

The fire teams are entering physical rooms set up as fire station 1 and 2. The physical equipment consists of 65" monitors and x-box controllers. Each fire team is usually manned by a team leader, one assistant and two smoke divers, the team leader uses the x-box controller. At each fire station the participants need to check in that they are present.

The team leader confirms that the two smoke divers are equipped with the fire fighter equipment: mask, suit (including glows), bottles and boots (check bottle pressure). The teamleader reports to the safety leader on bridge/safety command centre by use of radio. Based on where the fire is located and order from the safety leader, the team moves around in the virtual space utilizing the x-box controller in order to search for missing persons or fight the fire.

It is possible to search in cabines, open doors and walk around on all 7 decks. Visual effects like fire, smoke, water and lights are included in the visual scene.
The team leader decides to stop and split, typically into an area where only the smoke divers can access. The smoke divers must put on masks, check bottle pressure, open for air and enter into a new simulator station. This station is recommended to be separated next door to the other station. When the fire team members meet, they will see eachother as avatars.

Figure 2. The Fire Station

From the instructor station the general arrangement of the ship is available in 2D mimics. The instructor can monitor what the fire teams are doing in the virtual world, the status of fire detectors, doors, victims etc. Popups are available for the instructor to activate fire and smoke detectors in the hotel area and the complete engine room. When a fire is activated and not extinguished within a certain time it will spread to the other rooms. The time delay for spreading of fire is adjustable for the instructor. Virtual victims can be located around the ship by the instructor and they can be programmed if they are going to be conscious or not. The focus when using the simulator is communication between the teams, the fire teams must report back to the management team what they see and do in the virtual world.

Figure 3. Fire and Victim in a Cabin

Manual callpoints and fire extinguish equipment are located around the ship. The fire team can use handheld fire extinguishers and fire hoses. Water mist system can be activated from the bridge/safety command centre, both manually and automatically.

The instructor has the possibility to set flooding on all decks. The flooding will only be seen by the fire teams in the 3D environment. The fire teams need to report back to the management team what they see, and this can affect their response strategy. In addition, the lightning can be controlled with normal and emergency light to total blackout on the entire ship. The fire team can then use flashlights in the 3D environment when blackout occurs. The physical light in the room can also be interfaced to the simulator.

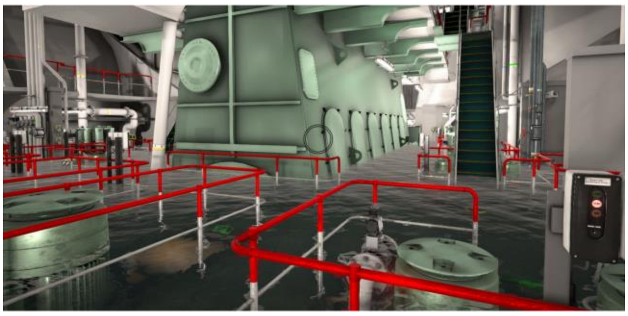

Figure 4. Flooding in Engine Room

To make the simulation scenario even more realistic sound system is included with engine sound, general alarm, fire alarms, abandon ship and so on.

The Instructor System

K-Sim Safety includes the same state-of-the-art instructor, monitoring and assessment system as Kongsberg's K-Sim Engine and -Cargo simulators.

The Instructor system enables a complete overview of the situation. It can easily configure different types of emergency scenarios like set fire, smoke, blackout, flooding and missing persons. Scenarios and fault-settings can either be programmed or manually set by the instructor during the exercise to dynamically challenge the teams. When the exercise is programmed, the scenarios will be set automatically. The same exercise can be run for different participants over and over again. Programmed exercises consist of so-called triggers. Triggers are made by use of Boolean algebra and all the dynamic values in the simulator are available and can be used to make triggers. Examples of dynamic values in the simulator can be fire detectors, smoke detectors, manual call points, pressure of fire extinguishers, fire valves, fire hoses, fire pumps, ventilation dampers/fans, victims, team members present, team members equipment, doors, light, temperature-, pressure-, flow-transmitters etc.

The instructor system contains of a flexible assessment system which can be programmed to give positive or negative score for the participants. The assessment system uses triggers the same way as described for the automatic scenarios. Kongsberg Digital is a vendor of the K-Sim Safety simulator, but it is up to our customers (training centre, schools, ship companies etc.) how they use the simulator and the assessment system for their advanced firefighting courses. To have a score in the assessment system, the instructors need to program this into the exercise with positive or negative scores for the participants.

To check that the fire team is present, fire team is manned, persons saved, air left for the smoke diver, fire extinguished, fire doors closed, time used for the different operations and so on are all things the instructor can check manually when running the exercise.

The instructor can start, stop and freeze the exercise at any time. Functions like record and replay are also available for the instructor when running debrief with the students afterwards. Automatic recording of what is done in the simulator during the exercise is always available, no programming is needed for this. In addition to the recording, an external CCTV system can be used for the debrief session evaluating for example the STCW criteria's for competence.

Figure 5. The Instructor Station

K-SIM SAFETY USED FOR RESEARCH

Kongsberg Digital is involved in a 4 years research project together with InnoTraining, University of South-Eastern Norway (USN), Institute for Energy Technology (IFE) and Politecnico. The project started in 2017 and will end in 2021, it involves 1 PhD student and several master students. The mission is to study virtual and augmented reality in education and training. Kongsberg Digital is delivering K-Sim Safety as a part of this research project. A dedicated area/section in the virtual software where the smoke diver can enter is going to use VR goggles instead of the x-box controller as user interface.

The project will focus on these three ways of running advanced firefighting courses:

- Traditionally table top exercise without use of the simulator
- Use the simulator with x-box controller
- Use the simulator with VR goggles

The experiments will focus on cognitive (what ears and eyes observe integrating with prior knowledge), skill-based and affective (attitude, motivation, self-efficacy) outcomes for the students. The experiments with K-Sim safety simulator has not started at this moment.

CONCLUSION

An onboard fire is a stressful situation which, if a crew aren't properly trained, can lead to panic, confusion and indecision, with potentially lethal consequences. Rigorous training is essential if crews are to tackle vessel fires in an efficient and coordinated manner. Learning fire safety processes in principle is one thing; but to fully comprehend the diverse strategies, actions and collaborative processes that can potentially save the life of crew with a real onboard fire, repeated training is essential – without exposing crew to actual danger.

Kongsberg Digital's high-fidelity K-Sim Safety **s**imulator solution is a very good tool to make the training more realistic. The full mission simulator including equipment at safety command centre/bridge, 3D environment with avatars, sound system, light system and CCTV system will make the participants feel that they are in a real emergency and will take their roles more seriously. Kongsberg expects that this will make a better training experience compared to standard table top exercises. K-Sim Safety can provide the training tool needed in a very life-like setting, where only fire teams or full crew resource training can experience similar pressure that they face in a real-life situation onboard a ship.

Risk, Trust and Reputation in the Offshore Supply Chain

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Abstract - **Offshore cargo delivery operations are risky particularly during bad weather and when vessels rest in dynamic positioning (DP) mode alongside installations. These operations involve intense interactions among and between crew on Platform Supply Vessels (PSVs) and installations, and the risk involved is closely related to how these operators relate to each other. Based on ethnographic fieldwork and interviews with a PSV crew this article explores various dynamics of these relationships and provides insight into how PSV crews handle fraught decision making situations characterised by conflicts of interests between PSV and installations, complicated trust challenges and the need to balance the material risks of accidents against the social risks of a bad reputation.**

Keywords

Offshore cargo delivery, Platform Supply Vessel, safety, risk, trust, reputation.

INTRODUCTION[1]

Approximately 100 oil and gas installations are presently operating at the Norwegian Continental Shelf (NCS). All of them need a steady supply of cargo delivered by, in total, 70 Platform Supply Vessels (PSV) [2] running shuttle between land depots and installations. Delivering this cargo is a high-risk endeavour (Ptil 2008; Ptil 2011) particularly when PSVs approach and rest alongside installations and cargo is moved between them. (Kongsvik, Bye, Fenstad, Gjøsund, Haavik, Olsen and Størkersen, 2012).

Kongsvik et al. (2012) provide a comprehensive overview of the risks involved in cargo delivery operations. Loss of position incidents that lead to collisions between PSVs and installations is the most severe risk as they may lead to large scale disasters like the Mumbai High North explosion in the Indian Ocean in July 2005. A PSV ran into the platform causing a gas leak that ignited and a fire that killed 22 people. In Norwegian waters 122 collisions were reported between 1982 and 2015, six of which had the potential to lead to large scale disasters (Ptil 2011; Ptil undated).

Loss of position incidents that do not lead to collisions have lesser potential for damage, but they happen more frequently. Sixteen reports of such incidents, on fourteen different vessels, were reported in only four years, between 2014 and 2018. (Kvitrud, 2019). None of the loss of position incidents offshore Norway have so far resulted in deaths or injuries, but have caused pollution and material damage.

Handling cargo is the third risk category. This risk is lower than for loss of position incidents as the chance of a large scale disaster is minimal. The potential damage still severe, however, in the sense that human lives have been lost, and the frequency of such accidents is very high. The North Sea Offshore Authorities Forum reports that lifting and mechanical handling accounts for almost 50% of all fatal offshore fatalities (Ptil, 2008). This figure includes accidents within installations as well as those that happen on PSVs and during lifting, but still indicate the risk involved in handling cargo.

Cargo delivery operations have attracted a lot of attention from researchers seeking to identify and understand how unwanted events happen, and how to avoid them. (See e.g.; Antonsen, 2009; Antonsen and Bye, 2014; Bottema, Grol, Ladeur and Post, 2015; Hassel, Utne and Vinnem, 2014; Kongsvik et al., 2014; Kvitrud, 2011; Kvitrud, Kleppestø and Skilbrei, 2012; Kviterud, 2019; Pawelski, 2015; Solem, Kongsvisk and Anderssen, undated; Tvedt, 2014). The research presented in this article builds on some of this previous research, particularly a large scale interdisciplinary project carried out by Studio Apertura NTNU Social Research between 2001 and 2010 (see e.g. Solem, Kongsvik and Anderssen, undated; Kongsvik et al., 2012). That project was initiated to 'diagnose' and 'treat' a dramatic increase in collisions (from 2 in 1997 to 12 in 2000) and delivered a wide range of technical, crewing and organisational improvements that contributed to

[1] This research was carried out as part of the RISKOP research project, financed by industry partners, Stord/Haugesund University College and the Norwegian Research Council, that examined how risk is handled during cargo handling operations at the Norwegian Continental Shelf.

[2] The number fluctuates all the time and official records are not freely available. These figures have been provided by the ship broker firm Clarkson Plato AS in April 2019.

bringing the number of incidents back down to 1997 levels.

One of Studio Apertura's core assumptions was that *"safety is often a question of cooperation, it is therefore important to focus on what goes on between groups of actors"* (Solem et al., no date, p 8, *author's translation*). The research found that low levels of trust between actors was a major underlying contributor to the accidents and a number of successful changes were introduced to improve the trust. Interestingly enough, however, the research stopped after having identified *that* low levels of trust was a problem and did not proceed to try and find out *why* and *how* the trust was low in the first place as well as the details of *how* the low trust decreased safety.

This article continues where the Studio Apertura research left off. It is based on extensive fieldworks on offshore vessels, primarily PSVs offshore Norway, but also in Malaysia, Australia and in the UK sector. On the basis of this material it focuses on organisational factors such as cooperation, respect and disrespect, the kinds and levels of trust between operators, how they think about each other and how all of this influences the high risk decisions that operators make as operations unfold. It primarily explores what the trust in relationships between seafarers and crews on installations consists of, how it is generated, and how it influences the risk of cargo supply operations.

In short, the research aim of this article is to provide insight into how PSV crews handle fraught decision making situations characterised by conflicts of interests between PSV and installations, complicated trust challenges and the need to balance the material risks of accidents against social risks of a bad reputation.

BACKGROUND

The cargo supply chain in the North Sea has been described elsewhere (see. eg. Pawelski, 2015) and a comprehensive description will therefore not be presented here. Some discussion of platform supply vessels and their destination installations need to be presented, however, so that the rest of the article makes sense.

PSVs are purpose made for the jobs they do and are basically quite similar. Some important differences exist, however, such as engine type and size and the number and kinds of propellers. Such factors determine the boundaries for what kinds of weather conditions each vessel can handle while resting in DP mode alongside an installation. Every PSV has its particular advantages and limitations, and just because one PSV is able to handle a particular set of weather conditions does not mean another PSV can handle the same.

Two different types of PSV crew perform essential cargo delivery tasks: Bridge officers and deck crew. Bridge officers make and execute overall navigational and safety decisions. Deck crew carry out decisions made by bridge officers, but also make and execute decisions about specific tasks like signalling to installations crane operators when to begin the lift. These two categories of PSV crew are the focus of attention in this article. Engine crew are generally not directly involved in cargo delivery and their most important task is to ensure that the technical equipment does not break down causing a 'loss of position incident'.

Two types of manned installations at the Norwegian Continental Shelf receive cargo from PSVs: Stationary installations that extract oil and gas, and floating platforms involved in exploration. Stationary installations are larger than floaters and require large amounts of cargo to be delivered on every cargo run. These installations exist for many years and are usually served by PSVs on long term contracts. This means that even though the actors involved never meet face to face, they become accustomed to each other. The PSV crews also learn about the peculiarities of these installations, such as wave patterns and currents that affect the handling of the vessel when in DP mode. Floaters are smaller, usually have far less storage space and never stay for long in each position. They therefore need smaller amounts at each delivery, but frequently more urgent deliveries. As these platforms move a lot the PSVs are often hired on the spot market, and the PSV crews do not build up knowledge about the specific risks at each platform.

As part of the Studio Apertura research Kongsvik et al. (2012) analysed the existing safety barriers employed to minimize the risk of unwanted incidents in the cargo supply chain. They concluded that one of the most risky part of cargo delivery operations is the phase when PSVs rest in DP mode along installations, particularly during bad weather, and argue that tensions in relationships between of PSVs and installations is an important risk factor during this phase. They also found that PSV crews can experience time pressure because installations emphasize efficiency over safety and that installations exert pressure to deliver cargo when the conditions are at (or beyond) the limit of what PSVs consider safe. Transgressions of weather restrictions happen, partly due to time pressure, but also due to assessments that underestimate the severity of the conditions. In total, the researchers found that PSVs frequently do not trust installations and the oil company to a great extent.

Relationships between crew on PSVs and installations are the focal point of this article. Even though cargo delivery operations have been extensively researched, the relationship between installation and vessel is still understudied. The few articles that deal with this relationship all argue the same point; that the balance of power in this relationship is structurally uneven and heavily in favour of installations (Antonsen 2009, Kongsvik et al., 2012; Solem et al., no date). This point is convincingly argued for and will therefore be taken for granted and not problematised in this article.

METHOD

This article explores dynamics in relationships between crews on PSVs and installations. It builds on material gathered through ethnographic fieldwork, semi-structured interviews and informal talks with informants, predominately PSV bridge officers and deck crew. Seven anthropological fieldwork settings were observed, four offshore Norway, one offshore Australia, one offshore Labuan in Malaysia and one offshore Scotland[3]. Each fieldwork lasted three to five days.

In addition to field-observations formal semi-structured interviews with one PSV crew was conducted to obtain more specific data on some of the topics observed during fieldwork. Informal talks with ship brokers has provided data corroborating information obtained through fieldwork.

The fieldwork included interacting with officers on the bridge, hanging out in the 'dirty-mess' with the deck crew, observing ABs at work on deck as well as participating in everyday activities such as eating with the crew, lounging in the TV room, working out in the gym etc. All the fieldworks were conducted according to methodological standards in contemporary social anthropology (see e.g. Oakley, 2013; Robin and Sluka, 2012; Whitehead, 2005) and extensive notes were taken throughout.

Participant observation implies continuous interactions that include dialogue that varies from small talk to "informal conversational interviews" (Allen, 2017). The latter typically evolve spontaneously from everyday conversations when these turn to topics that the researcher finds worth inquiring about in greater detail. A conversation can thus gradually turn into an 'interview' in the sense that the researcher asks more detailed and pointed questions than what is common for actors who just work together or socialize (Whitehead, 2005). When they are finished informants may not even identify them as 'interviews'. The questions during these 'interviews' generally revolved around safety procedures, and the crew-members thoughts and practices around these. Nevertheless, all conversations (whether classified as informal interviews or not) were recorded, and depending on the method of classification, between 25 and 50 informal interviews were conducted during this research.

Observations began with a broad scope, and gradually became more focussed as the issues that were important to the crew became clearer. This also meant that the relationship between PSVs and installations gradually took central stage. Studying relationships is what social anthropology is about, and when interactions happen in face to face situations they usually lead to rich in detailed descriptions of the relationships and their dynamics. Relationships between crews on PSVs and installations are different because interactions they only exist in communications via media like radio, phone and email. Consequently these relationships are difficult to observe directly (usually I could not listen in on the radio) and the observations seldomly yield the same rich details as when all interacting actors are observed at the same time. I obviously listened to PSV crew talk about installation crew, but as I was never given an opportunity to do fieldwork on installations I never observed that side of the relationship. Consequently the relationships described and discussed here have only been observed "once removed", and the descriptions are of "virtual" relationships as they are imagined by the researcher on the basis of observations of PSV crews. This may, of course, reduce the validity of the data. On the other hand, my observations are congruent with those of several other researchers (Antonsen, 2009; Kongsvik et al., 2012; Solem et al., no date).

SAFETY THEORIES

The research literature on safety is large and it is not possible to even sketch an overview of it in this article. Instead I present some highlights from the literature, as well as my own reflections, that either inform or provide the theoretical context for the analysis.

Contemporary safety research builds on two contrasting models of what safety is and how it is achieved (Dekker, 2004) The engineering model still dominates the field (Bieder and Bourrier, 2013), but

[3] The latter three fieldworks are included for comparative purposes

a model based on social science is gaining ground (Gilbert, Amalberti, Laroche and Paries, 2007). The engineering model tends to be top-down, rationalistic and optimistic. It assumes that all risks can be discovered and removed through logical analysis and implementation of the correct procedures. The social science model, on the other hand, sees safety behaviour as routines that develop from bottom-up, emerging from experience. It studies "*What usually happens in the normal course of high-risk activities*" (Gilbert et al., 2007, p. 969) and assumes that reality is too complex to create procedures for all eventualities. It argues that deviations will always happen and sometimes are necessary in order to actually act in a safe manner. Providing room for practitioner discretions is thus necessary as it is the practitioner who will be at the site if and when something is about to go wrong and that the procedures may not address.

The present article builds on the latter approach (i.e. social science) and investigates "*the real conditions under which safety is produced*" (Bieder and Bourrier, 2013 p. 4), but from a different perspective than what is common in safety research. Social scientific safety studies usually focus on individual behaviours; i.e. on what actors do (Dekker, 2004); on organisational or structural conditions influencing or constructing the context for what individuals do (e.g. Perrow, 1984) or the ideas (beliefs) and emotions that supposedly influence what individuals do, e.g. studies of Safety Culture (IAEA, 1986).

The focus here is different. I wish to understand how relationship factors between operators generate safety, danger and risk. This perspective is presently lacking in much of safety science. To the extent that relationship factors (such as trust, identity and belonging, commitment and legitimacy) have been studied these factors have been conceptualised as singular ideas or emotions (Conchie, 2006; Jeffcott, Pidgeon, Wayman and Walls, 2006) or as isolated effects of ideas (Luria, 2010) rather than as emerging from relationships among operators.

The absence of a relational perspective is remarkable considering that most risky operations are complex co-operations; interplays between and among a number of individual operators who constantly act and react to each other. Understanding how safety is achieved thus necessitates understanding relational attributes such as how trust and trustworthiness is generated, how and why and when acts of subordination or deference unfold, how reciprocal acknowledgments of respect or contempt constitute the actors in relation to each other, etc.

TRUST; A HEURISTIC CONCEPT

Trust is an ambiguous term (Bauer, 2014) with both emic and etic (Morris, 1999) meanings. In simple terms emic is the "common sense" meaning of a word, sign, metaphor etc. Emic terms are often ambiguous and one term may refer to many different concepts (ideas) at the same time. Etic, on the other hand, refers to terms and concepts developed by academics for the purpose of scientific analysis. Etic concept therefore need to be precise and clearly defined.

As an emic term trust is very rich, fundamentally ambiguous and used in connection with anything humans can doubt or be uncertain about, but still wish to predict and relate to 'as if' the uncertainty did not exist (Deutsch, 1958). Academics have tried, and failed, to transform this ambiguous emic term into a clearly defined analytical (etic) concept to be used for scientific analysis (Bauer, 2014; Ashleigh and Stanton, 2001). Already a decade ago more than 70 different definitions of trust existed in the field of organisational studies alone (Seppänen, Blomquist and Sundqvist, 2007) and in 2006 Cox, Cones and Collinson concluded that no universally accepted etic definition of trust existed at that time. Bulatova reached the same conclusion in 2015. Literature claiming the opposite has not been found and it is thus reasonable to assume that a clearly defined scientific definition of trust has still not been created and universally accepted.

When a concept remains ambiguous in spite of great effort to clarify it, it cannot be used as a scientific concept. It may, however, still be useful as a heuristic; as a tool for making inferences and directing one's thinking in certain directions. That is how it is used in this article. And, as in everyday conversations when people use ambiguous terms, the meaning gradually becomes clearer by the way it is used.

Trust and risk

Trust is is intrinsically linked with risk (see e.g. Bauer, 2017; Holmström, 2007; Luhmann, 1988; Luhmann, 1979; Mayer, Davis and Schoorman, 1995) in the sense that there is no need to trust anything if there is no possibility of anything going wrong. It is only the moment that it is possible to imagine a negative deviation from what we would want to happen that it makes sense to say that we trust that the outcome will be good.

Understanding trust therefore necessitates a few words about risk. Within risk management risk is usually defined as the probability of an undesired event multiplied by the magnitude of the consequences if the event were to happen. This may be a good definition for the purpose of quantifying risk, but it is not useful for understanding how humans handle risk in everyday situations. As Kahneman (2010) has shown, most humans have great problems grasping what probability is about. Consequently this paper takes the position, in line with Luhman, (2001), that the common sense meaning of risk has more to do with uncertainty than with probability and consequence.

Risk and trust are thus both about uncertainty and trust can be understood as a strategy for managing the uncertainty that makes something risky (Luhman, 2001, p. 95). According to Luhman humans only have two, mutually exclusive, options when facing uncertainty. We can try to control that which is happening or we can abandon our desire to control it and have faith that all will go well. In practical terms both achieve the same: To establish a *sense* of certainty in situations where real certainty cannot be achieved. *(*Luhmann, 1979 in Möllering, 2001, p. 409). The strategies achieve this result in radically different ways, however. The latter, which Luhman calls ‘confidence’, seeks to overcome uncertainty by ignoring it and promotes habitual behaviours as if no doubt exists. The former, which Luhman calls ‘trust’, embraces doubt, explores it, seeks to eradicate it as far as possible and then deliberately choses one less risky course of action over several others that are more risky. Doubt is never abolished, however, as no one can ever know with absolute certainty what the future will bring.

Trust is a value

A strategy is a general model for achieving something valuable. In the case of trust this valuable is both trust in itself, and other valuables that trust is a means to achieve. Trusting others is a positive experience (i.e. valuable) when the others are trustworthy and the trust is honoured. Reciprocated trust is even more valuable. But trust is rarely only an end in itself. It is usually valuable as a means to secure some other valuable that could be lost or destroyed. These other valuables are things like life and health, honour and shame, a good reputation, fellowship etc.

When humans interact they generally strive to optimise their values; i.e. to maximise gains while simultaneously minimising losses (Barth, 1966). This means humans do not always try to maximise gains. In some situations it is more important to avoid or cut losses, and individuals may therefore fail to take advantage of opportunities that could lead to a gain out of fear that they might fail, and thus incur greater loss than if they did nothing. Optimisation of values also takes the form of balancing different values against each other. Values frequently do not harmonise, and may even be directly in conflict with each other. The point is, when trying to understand why people act as they do it is necessary to take into consideration that they may seek to optimise several (possibly conflicting) values at the same time, and that the desire to avoid a loss of one kind of valuable can overrule the desire to profit on another

Trust, then, is a value that humans seek to optimize in specific interactions. They also seek to optimize the values that trust is a means to achieve. Such balancing acts may lead to a number of different outcomes, and when seeking to understand trust it is thus necessary to keep in mind that trust is never fixed and humans do not trust in general. We always trust specifically in relation to other specific values that are at stake in specific contexts (Mayer et al., 1995; Schoorman, Mayer and Davies, 2016). This means that trust changes and varies; just because it is possible to trust a specific person in a specific context, with regards to a specific value, does not mean that one can automatically trust the same person with regards to another value in the same context, or the same value in a different context. Every time we trust someone there is also a risk of getting it wrong in spite of previous experience. A person may have been a safe operator for 30 years, and his colleagues may have very good reasons to trust him. That does not mean he is incapable of making mistakes, of losing his competence, or of turning against his colleagues in the future.

Trust is thus always fraught; it is never achieved once and for all and it can always be lost.

Trust and Trustworthiness

This brings us to yet an important point for how trust is understood in this article. As a relational concept trust only exists in tandem with trustworthiness. If trust is a strategy for overcoming uncertainty through a process of exploration, that which is uncertain is the trustworthiness of the other.

Trustworthiness is generally conceptualised as consisting of three personal attributes: i) Benevolence (i.e. the intention to act in ways that will benefit the other); ii) Competence (i.e. to possess the knowledge, skills and resources needed to behave in ways that benefit the other) and iii) Integrity (i.e. to give and give off honest signs about ones benevolence and competence) (Mayer et al., 1995; Grimen, 2009).

In this perspective, the decision to trust someone means to assess the other person’s trustworthiness, to decide on a particular level of trustworthiness, and then to trust the other in accordance with that assessment. Such decisions are always precarious because the assessment may be wrong on any one of the three attributes. We may have good reasons to assume that the other is friendly and thus trust him, but still get hurt because he was not competent. Or we may believe the other is both friendly and has the necessary knowledge, but still get harmed because he did not have the resources needed to keep us safe. The classic scenario of countless Hollywood movies is that the other gives off false information about his trustworthiness and we get stung because we trusted someone with no integrity. On the other hand it is not without risk to be too cautious either. As Sørhaug (1996) points out, trust can only begin to develop if someone decides to 'give' trust before they have received any. If no one initiates trust it will not develop. Or even worse; deciding to distrust may result in the loss of a potential friend because we offended him by assuming that he was the opposite of trustworthy.

Trust, trustworthiness and safety

Safety researchers have been interested in trust for a long time and the predominant view is that trust has a number of positive influences on safety:

"Trust has been described as a lubricant for open and frequent safety communication (Reason,1997) and as a facilitator of effective safety leader- ship (Carroll, 2002; O'Dea & Flin, 2001). Trust has also been ascribed a role in the success of safety initiatives designed to improve safety attitudes and performance (Cox et al., 2004; Fleming & Lardner, 2001). Similarly, risk theorists have associated trust with effective risk communication (Kasperson et al., 1992), reduced risk perception (Viklund, 2003), and effective risk management (Siegrist et al., 2003) (Conchie and Donald, 2006, p. 1151).

As recent as 2017 Gausdal claimed that *"interpersonal trust (...) among seafarers, seems to be a prerequisite and an indirect factor, or mediating variable, that influence safety-related organizational outcomes positively and seems to reduce human errors."* (p. 197).

Other researchers see trust as a potential threat to safety, arguing that misplaced trust may lead to group think and decrease in personal initiative and responsibility (Conchie, 2006). Schoorman et al. (2007) claim that *"Trust is the 'willingness to take risk', and the level of trust is an indication of the amount of risk that one is willing to take*" (p. 346). In other words: High levels of trust equals high levels of risk. In an earlier publication he and his colleagues warn against "*"Blind" trust, defined as a propensity to "repeatedly trust in situations that do not warrant trust"* (Mayer et al., 1995, p. 715) claiming that such trust may increase risk rather than reduce it (Gausdal, 2017).

In my opinion these claims are misguided and rather useless for understanding how trust and safety are related. A logical inference from the previous section is that problems with trust do not emerge unilaterally from the trust that is given. Problems only emerge when the trust we give does not match the trustworthiness of the person we give it to. For most safety science purposes it is irrelevant how much one operator trusts another if the trustworthiness of both in relation to each other is not taken into account.

Influence between trust and trustworthiness

In a safety perspective benevolence, competence and integrity matters more than trust. When operators are benevolent they will actively try to avoid hurting others. When they are competent they are able to avoid hurting others, and when they have integrity others can be sure that the signs they give off about their friendliness and competence are true. Hence, when people are trustworthy they also act in safe ways. The same does not necessarily hold for trust. People vary in their ability and willingness to trust others, but regardless of what the willingness and ability may be it does not say anything about their benevolence, competence and integrity. Trustworthiness is thus directly related to safety, and trust is not. Trust and trustworthiness influence each other, however, and in order to understand how trust influences safety it is necessary to begin by understanding the mutual influences between trust and trustworthiness.

DeSteno (2014) argues that people become trustworthy when they need others, and therefore need to trust others. In general, he claims, people are more likely to trust other people who are trustworthy and they are also more likely to be trustworthy when they are trusted in return. This argument make sense at an abstract level and for post hoc explanation of how trust develops. It does not, however, provide an adequate understanding of how trust and trustworthiness plays out in real life when actors do not have the benefit of hindsight. In other words, how specific actors, in specific contexts, try to assess each other's trustworthiness without having much information about each other.

In such situations all the actors face the same challenge: To assess and judge the trustworthiness of the other, and then give the amount of trust that matches the trustworthiness the receiver actually will demonstrate. All manner of things can go wrong in this process. The less information - the greater uncertainty about their trustworthiness, and thus the greater the risk of trusting. On the other hand, not showing enough trust can offend the other; showing trust too late can make the other suspicious; and showing too much trust too early can allow the other to take advantage of the one who shows trust.

Maximum safety is obviously achieved when all the actors are highly trustworthy and also give each other a lot of trust. Giving trust that is not matched by trustworthiness is, on the other hand, very dangerous. Getting the assessment right, so that trust matches trustworthiness, is highly difficult and safety is reduced from errors on both sides.

In sum, trust is always an issue when anything valuable is at stake and there is some degree of uncertainty about what the outcome will be. Trust, the assessment of the trustworthiness of the others and the decision about how much to trust is the basis for overcoming this uncertainty. Getting the assessment right so that one trusts the other to the same degree that the other is trustworthy leads to an optimal outcome. Lack of information about each other is an obstacle to getting that assessment right, and as such lack of information about each other increases the risk and reduces safety.

FINDINGS AND DISCUSSIONS

As mentioned the research aim of this article is to provide insight into how PSV crews handle fraught decision making situations that are characterised by: i) conflicts of interests between them and installations; ii) complicated trust challenges and iii) the need to balance the material risks of accidents against social risks of a bad reputation.

Before I present my findings I wish to highlight a few important contextual factors. First, that my observations indicate that relationships between PSVs and installations are predominately friendly and that they usually cooperate efficiently, effectively and safely. As this article focusses on 'negative' aspects of these relationships it is important to keep in mind that this does not dominate these relationships. The 'negativity' relationship dynamics described and analysed in this article only emerge under specific circumstances.

Secondly, that this article is only concerned with factors that influence a limited number of aspects of cargo delivery operations that have been identified as particularly dangerous.

Thirdly, that relationships between PSVs and installations only exist via technologies like radio, telephone and e-mail. The researcher could therefore never observe these relationships directly, and relied on observations of PSV crew, plus their work stories.

Apart from the crane operator PSV crews rarely have detailed information about what kind of crew they have been dealing with at installations. This contributes to a general tendency for PSV crews to talk about installations as total entities, not as teams made up of several different kinds of actors.

Fair weather irritations and disrespect

Every PSV fieldwork began with getting to know the crew and the ship. While we sailed I engaged in small talk with bridge officers and deck crew, asking questions about their jobs, and their answers frequently turned to issues in their relationships with installations. This preoccupation with the installations was common to all the PSVs I visited; offshore Norway and the UK, as well as in Australia and the South China Sea. The contents of the talk differed, however.

In Norwegian and UK waters their comments and stories about installations were peppered with negative sentiments, particularly about being treated disrespectfully. A classical story was about installations that discharge dirty liquid or powder over the vessel as it rests below the installation[4]. They also complained about lack of planning; installations that delay or interrupt operations without giving the vessel any information about what is happening. Less frequent stories are of installations that put pressure on them to deliver cargo under dangerous conditions; or to accept undocumented backloads (i.e. cargo to be returned to depots).

Antonsen and Bye (2015) found the same stories, but refrain from discussing their truth-value, arguing that they should rather be understood as "myths" (p. 131) that express a communal identity, and a common moral. In that sense the stories primarily say something about relationships among the seafarers rather than between seafarers and installations.

I agree that such stories may be understood as myths, but believe that they also say something important about relationships between PSVs and installation at the NCS. As mentioned, I collected such stories on all the PSVs I visited, and the stories I heard in Australia and Malaysia carried specific messages about the relationships in those contexts. There is no reason to assume that the Norwegian stories should only be interpreted as myths, and that they do not contain valuable information about the relationships between vessels and installations as well.

[4] Antonsen and Bye (2015) have made the same observations and confirm that discharge over vessels is a long standing problem.

These 'fair weather irritations' have been described elsewhere (Antonsen and Bye, 2015) and will therefore not be discussed here. They show, however, that PSV crews are used to being treated, by installations, in ways that PSV crews find disrespectful and condescending. These experiences are significant as background for understanding the tensions that may build, and the conflicts of interests that may come to the surface, when the weather turns bad.

Weather window

During stormy periods PSVs leave port when storms are still raging and weather windows[5] are likely to open at the oil field in the near future. The vessels then sail for ten to twelve hours through strong winds and high waves before reaching their destinations. PSVs are built for such conditions, and the sailing is not very risky, but frequently means that the crew did not sleep well during the journey. Consequently they may already be rather tired when the lifting operations begin.

At their destinations the PSV duty officer assesses whether a window has opened and if it is safe to get close to, and rest on DP next to the installation for the duration of the lifting operation. The risks are different for every location and every installation. Even resting on different sides of the same installation may offer different risks[6].

Judging weather conditions in open seas is not an exact science. Conditions are perceived differently from a ship and from an installation, and the former may judge the weather as still too harsh when the latter judges it as OK. Whereas seafarers have an immediate experience of how the waves and currents influence the vessel, installation crews do not. Winds, currents and waves interact in ways that affect the vessel in ways that most installation crew do not understand. In addition PSV officers must consider the technical capabilities and limitations of their vessel, a challenge that installations usually do not consider and are not qualified to do.

If the window is still closed when a PSV arrives the duty officer must decide whether to wait near that installation or go on to the next. The longer the weather has prevented supplies, the more critical the installation needs it. In such situations installations may become very insistent that the PSV stands by, ready to supply the moment the window opens.

Waiting on a window can be demoralising to the crew who become both tired and impatient. It is also inefficient as a window may be open at another installation during this time. PSVs usually serve several installations on every run and cannot wait at one installation if it is possible to deliver at another. The PSV officer may thus initiate a change of sailing plan, and ask the traffic control centre for permission. This could, however, be a serious problem for the installation because the weather window may open after the PSV has left, but close again before it can return.

The consequences of a shut-down are, obviously, far more immediate and severe for an installation than for the PSV that serves it, and the pressure on the installation to avoid a shut-down is considerable. The installation may then transfer that pressure (Kongsvik et al., 2014) onto both vessel and control centre to ensure that the PSV remains stand by to deliver at the first available opportunity.

If the commanding PSV bridge officer determines that the weather window is open the cargo delivery operation will begin. Winds, waves and currents exerts huge force on PSVs and their engines and propellers have to run at high speeds to produce the counter force needed to keep the ship in a fixed position. In addition, winds and waves constantly change and the ship has to constantly adjust. Even though the DP computer calculates the forces and the changes, the DP officer needs to closely monitor the instruments to ensure everything works properly. A number of faults may happen, such as loss of signals for the DP or an engine may approach overload. Meanwhile, the other bridge officer monitors the delivery process; documenting the cargo that is on- and offloaded, the conditions on deck and how the lifted objects behave in the wind.

In addition to monitoring the DP and the delivery, the officers also closely follow how the weather is changing. Weather can change fast, and just because a storm is decreasing does not mean winds and waves are calming down smoothly. They may also pick up again and the window can close at short notice.

[5] A weather window is a technical term for conditions that need to be met in order to consider it safe to carry out a specific operation during bad weather. The specific criteria vary depending on the operation. For cargo delivery operations significant wave height should, as a general rule, be no more than 5 metres and middle-winds should not exceed 20 m/s (Norsok R-003 2017). Conditions below these thresholds should last 50% longer than the period the operation is planned for. For a more detailed discussion see Røyrvik (2012).

[6] Finding confirmed by Kongsvik et al. (2012)

As mentioned two of the fieldworks at the NCS took place during a winter when storms had raged more or less continuously for months before the fieldworks took place. On both of these trips I observed prematurely aborted operations. Two of the observed processes leading to the decision to abort provided valuable insights into factors that significantly influence relationships between PSVs and installations:

The PSV had experienced several aborted operations over the last few months, and the installations were starting to get nervous that they would run empty of bare essentials and need to stop the production. Even on this run some of the operations had been prematurely aborted. As our vessel approached a new installation all parties were thus highly motivated to get the cargo delivered, and the commanding officer judged the conditions good enough to begin the lifting operation. After about one hour the weather deteriorated. The officer on the PSV and the crane operator communicated intensely about the conditions, exchanging comments about wave heights and wind speeds. The exchanged information was very technical and brief however, with comments like: "Wind just hit 38 knots", "That gust hit 40". The gusts bringing the wind speed over the limit occurred more and more frequently and suddenly the crane operator exclaimed: "No, that is it. We abort. It is not safe to continue". I sat right next to the officer in charge and could see a wave of relief wash over his face as he spontaneously slung his outstretched right arm, with a clenched fist, into the air and exclaimed: "Yes! It was they who stopped, not us".

The exclamation came spontaneously and without any obvious intent but to express relief. However, to me it also carried the message that to abort a delivery operation is a serious decision, and that it matters how the decision is made, and who makes it. This impression was reinforced by another aborted operation on a different field trip at a different vessel.

The weather had been rough for months and at this particular cargo run the PSV had managed to deliver cargo at the first and third installation, but had had to abort midway through the delivery at the second. As mentioned conditions are always somewhat different at different locations and when they arrived at the fourth installation the weather window was open. It gradually began to close during the delivery and AB's, officers and crane operator worked as fast as they could, communicating intensively about the wind and the waves. The DP officer kept a keen eye on the quality of the DP signals, and monitored the strain loads on the engines, the speed and directions of thrusters and azimuth.

The change from bad to awful weather was not gradual and smooth. The wind came in gusts and the waves in uneven frequencies, heights and directions. While the operation unfolded the wind hit the 40 knots mark more and more frequently with individual gusts above.

As the conditions worsened the AB's increased their reporting of how they experienced it. Radio communication between DP officer, AB's and crane operator became increasingly intense. When the crane operator commented on a hard gust, the officer would confirm "Yes, my wind gauge just hit 42". Then a comment from one of the AB's "The waves are really picking up. The last one gave us a good jolt". "Yeah, I saw how it sprayed you" the officer responded. "Can't go on for much longer" the crane operator commented. "Yeah, I agree" the officer said, and then the AB let out a yell "Whoa, that was a tough wave. This is not good." These exchanges continued for approximately 10 more minutes, and then the crane operator exclaimed. "No, that's it. This is just getting worse. I reckon we should stop, what do you think?". "Yeah, I agree" the DP officer responded. That was the final word, the officer then radioed to the AB's to quit, the operation was over and the PSV continued to the fifth installation.

Even though the operation was technically over it continued to hold the attention of the crew. The officers and AB's talked about it at length over dinner, and even the next morning at breakfast; going over and over how the wind and waves had behaved, what each one had said, how the crane operator had agreed all the way and confirming to themselves that stopping the operation was the right thing to do.

Uneven power, conflicting interests

Both cases demonstrate that the decision to abort is not taken lightly. This begs no further explanation; it is in everybody's interest that the installation receive the cargo they need to avoid shutting down. It does beg another question, though: Why is it so important how the decision is made, and by whom?

In the first case the officer's face expressed relief; a tension was released. This means something important had been going on; something was at stake. At the same time his exclamation "*It was they…. not us",* combined with a clenched fist thrown high in the air, carried a strong underlying message of victory and bravery. In other words, the PSV had not 'lost'; it had 'won' and the installation had 'chickened out'. In the second case there was no 'victory' over the installation and no sense of competition about being brave. There was, however, an intense informal 'debriefing', and a release of tension, as the PSV sailors celebrated how well they had handled the situation, and how well they had cooperated with the installation. This begs further questions: What are the factors that generate these tensions and such relief when the decision is made? And why were the two cases so different when they are both the same decision making process; i.e. when to abort the operation?

The case I argue is that in spite of apparent differences the behaviours in both cases were generated by the same underlying factors: A context where PSVs have less power than installations, and significant potential conflicts of interests exists between them.

These conflicting interests are:

- Installation only needs to think about its own needs, whereas PSVs need to consider the total delivery schedule.

- PSV crews have intimate knowledge of the safety limits for their vessel whereas installations do not.

- Time at sea is a burden for PSV crew, and not for installations.

It may therefore be in the interest of a PSV to abort an operation, or refuse to stand by for a window to open, when it is in the interest of an installation that the operations continues, or that the PSV waits until the weather improves. Combining these conflicting interests with the uneven distribution of power and the possibility of being treated with disrespect, goes some way towards making sense of the tensions that emerged in the two cases described above. PSV crews have good reason to be wary of making unilateral decisions as they have reason to suspect that their decision may be ignored or overturned by installations. Antonsen and Bye (2015) provide empirical data supporting this argument, showing that the oil company may not stop at disrespecting safety decisions made by PSV, but may go as far as accusing the PSV of using safety procedures "against" the oil company, as if the decision to act safely was merely a means to defy the rightful authority of the oil company (p. 138)

Understanding the uneven distribution of power, plus this conflict of interest, is thus necessary to understand relationships between PSVs and installations at the NCL. It is not sufficient, however, because these two factors are relatively easy to articulate and codify and are, in fact, clearly expressed in the foundational guiding principle pervading the NORSOK R003 standard for safe use of lifting equipment at the NCS (Standard Norge and Norsok, 2017). This guiding principle is that that any operator who believes that an operation is no longer safe has the right, and the duty, to stop it. Even though this principle is not formulated as a rule it permeates the standard. It was also frequently referred to, by seafarers, during all the fieldworks offshore Norway, and PSV crews firmly believe that they have this right. However, if this principle truly governed these relationships it should never be a problem how the decision to stop was made, nor who made it.

Consequently, something more than this must influence how these operators reach these decisions. My argument is that the missing pieces in the puzzle include trust, respect and reputation.

Trust and respect between PSVs and installations

As mentioned trust is an issue whenever anything of value is at stake and when there is a relatively high degree of uncertainty about the outcome of the interaction where that value is at stake. In this situation there is absolutely something at stake. In the worst scenario both vessel and installation explodes. In a slightly less serious scenario the installation has to shut down. There is also uncertainty. As mentioned PSV crews never interreact face-to-face with installation crews. In addition they never know whom they are interacting with at any particular time. The crew on installations vary and though the PSV crew may recognise the voice of someone they have dealt with before, they frequently do not.

Theories about trust are almost exclusively concerned with face-to-face interactions, or interactions between individuals and institutions. Hardly any studies exist of trust in interpersonal relationships between individuals who are "once removed" and therefore have minimal information about each other's identities. Still, even without empirical research data it is clear that such interactions necessarily imply large measures of insecurity about the trustworthiness of the other party.

In the above cases it is clear that the PSV crew had very little information about the trustworthiness of crew they interact with on the installations. In both cases the interactions unfolded gradually, and lots of technical information was exchanged. In the first case the information was accurate but said nothing about how the crane operator judged the situation. Consequently the PSV officer did not have any indications about which way the crane operator was leaning regarding a decision to abort. Being uncertain the PSV officer had to rely on his assumptions about the trustworthiness of installation crew in general, and consequently he did not take a chance on stopping the operation.

In the second case the interactions unfolded quite differently. The flow of information increased as the conditions deteriorated. It was not the intensity of the information that made the difference, however, but the content. The communication was not exclusively about technical issues, but peppered with judgements about how “bad” it was getting as well as acknowledgements of each other’s situation. The crane operator even included questions to the PSV officer, inviting him to participate in the decision. The decision in the second case was thus a consequence of a gradual negotiation involving all the actors as relatively “equal” participants in a common endeavour where all parties contributed to the decision to abort. The PSV officer gradually became less uncertain about the trustworthiness of the specific individual he was interacting with, to the point where he could trust the crane operator enough to make the final call.

The interpretation above provides a fairly comprehensive understanding of the factors influencing the decision to stop a dangerous operation, but still leaves some questions open. Above I claim that the values at stake for PSV officers are the physical safety of vessel and installation, to keep the installation operating and to avoid making decisions that installations may disrespect; i.e. ignore or overrule. Being treated with respect is a highly esteemed value among the PSV crews I observed and when people hold that value it is sensible to avoid situations where they are likely to be treated with disrespect. Developing behavioural strategies that will avoid provoking other actors who have might, and have the means, of treating them disrespectfully therefore make sense. Lacking sufficient information about whether the other actors are trustworthy, in the sense that they will refrain from treating the PSV crew disrespectfully, means that it is sensible for the PSV crew to not trust them too much until they have proved otherwise.

This explanation make some sense of the observed events, but still does not provide a fully adequate answer. The fundamental safety rule clearly states that any actor has the right and duty to stop an operation they believe to be unsafe. If this rule is taken seriously then there should be no fear of being treated disrespectfully, and no need for any more information in order to trust installation crews. Thus the question still stands: Why is this rule not taken seriously?

The following episode provided an essential clue to the answer.

The value of reputation

On my way offshore I travelled with some of the crew. The vessel had been late coming in from a cargo run and was in a port further away than originally planned. The journey therefore took a long time, and this gave us lots of time to get to know each other. I only had a week to complete the fieldwork, and as we approached the ship I asked if the changed location would matter. One of the deck officers said that it might, but then again, one never knows. “If the weather turns bad, and it has done that a lot recently, we may get stuck out there for weeks”. He continued saying that during their last trip the weather had been really bad, and they had had to wait stand-by for three weeks at an installation that was running very low on supplies. The waves were up to ten metres and they got really tired. I asked if it was safe to get so fatigued and he said: "Not really". "So, what would have happened if you had said it was not safe?" I asked. "It would have been aborted and we would have gone to shore", the officer answered. "Why did you not do that, then?" He shrugged and said: "The contract is up for renewal quite soon. If we had used the safety card and called it off, we'd never get it renewed".

Even though this observation was from the UK sector subsequent data substantiates my impression that the same factors exists, in principle, among PSV crews on the Norwegian side. Above I referred to an episode when an oil company accused a vessel of using the safety system “against” the oil company when the vessel judged the weather to be so bad it was not safe to sail. That situation illustrates that “playing the safety card” is risky on the Norwegian side too. It is not risky in a material sense. On the contrary; it would reduce the risk of material accidents. It is risky in a social sense.

The social value at stake in both these cases is reputation. Like respect, reputation is of utmost importance to Norwegian seafarers. (Antonsen and Bye, 2014) and all the crews on the PSVs I visited at the NCS were concerned about it. They all talked a lot about how theirs was "the best ship in the North Sea", comparing themselves with other ships that were, obviously, not as good as theirs. There was talk of other PSVs that were less service minded, that only do what they strictly have to according to their contracts, and who have reputations among the installations as "bad ships". The overt point of the stories is that "we are the best ship in the North Sea", but an equally important sub-message is that ‘there are bad ships, and we are not one of them’. They were also convinced that the other parties in the larger cargo delivery chain (installations, the oil company in general and the depots) spread rumours about them.

Antonsen and Bye (2014) provide substantial descriptions and argument in favour of this claim and these arguments will not be repeated here. From my observations it seems that having a good name was important for two reasons; on the one hand it is a matter of identity and pride, on the other hand because they believe a bad reputation may be detrimental to their ability to keep working in Norwegian waters. Whether this belief is true or not is immaterial. The important point is that PSV crews are convinced that it is true. That said, hearsay confirms that it may not be a far-fetched belief. Ship brokers on the west coast of Norway confirm that there are ships with poor reputations that clients will not even consider chartering.

An essential problem with reputation is that the person that the reputation is about has no direct control over it. Reputations are formed through processes of inferences, assessments and judgements that are privy to those who hold the opinions and the contents of the reputation is commonly not explicitly communicated to those it is about. Consequently it is fundamentally difficult for anyone to know, with a high degree of certainty, both what their reputation is and how they got it.

This high degree of uncertainty necessarily means that trust is fundamental issue whenever reputation is on the line. In the case of reputation it is fundamentally difficult to obtain knowledge about whether the other party is trustworthy or not. In relationships between crews on PSVs and installations this uncertainty is even greater than usual because their interactions are so brief and one-dimensional. PSV crews thus have to do a lot of guessing when interpreting the little information they receive. For a PSV crew to believe that an installation crew is trustworthy, and that it will give them a good name, the seafarers need information about the benevolence, competence, and integrity of the installation crew. From the perspective of the PSV an installation crew is trustworthy, and can be trusted to give them a good name, if the installation crew assumes that the PSV will reach safe and efficient decisions at all times. The installation is trustworthy if it takes for granted that when the PSV says conditions are too dangerous, then they are in fact too dangerous.

The PSV crews I observed had little reason to assume that installation crews think this way. Considering the potential consequences of a bad name it would thus be very risky for a PSV crew to assume that the installation crew they are dealing with in fact will give them a good name. Kongsvik et al. (2012) observed that PSV at times put pressure on themselves to continue operations when weather conditions are on the margins of safe. It is reasonable to speculate to what extent such "self-pressure" is a result of a desire to avoid getting a bad name in a situation where they do not have sufficient information about the trustworthiness of the installations they deal with.

Combining these insights (about the uneven balance of power, previous experience about being treated disrespectfully and the risk of getting a bad name) makes both of the cases described above far easier to understand. In the first case the communication did not contain sufficient information about the trustworthiness of the crane operator for the PSV officers to believe that he would refrain from giving them a bad name. When the crane operator then made a unilateral decision to stop the operation he also took the full responsibility for the abortion. In other words, neither he nor anyone else at the installation would be able to "blame" the PSV and say they called it off because they were not up to it.

In the second case the communication was far richer. Having built up towards a decision to abort, the crane operator made the call, but as a question. The PSV bridge officer actually gave the final word. In this case the PSV officer had received a lot of information that he interpreted to mean that the crane operator was trustworthy. The information was far from complete, however, but the officer made that final "leap of faith" and trusted that the decision would not be used against them later. The intense "debriefing" going on in the evening and over breakfast next day shows that the decision was still considered precarious. In the first case, after the crane operator had made a unilateral decision, the tension immediately dissolved. In the latter case the tension stayed with the crew for hours.

CONCLUSION

In offshore operations safety is one of the more salient values at stake, but not the only one. Profit is obviously another value, but so are respect and reputation. PSV crews need to juggle all these values in an attempt to gain on all parameters without losing on others. Most times this means losing some degree of gain of some values in order to minimise loss on others.

Risk is a matter of gains and losses. In everyday speech we say that the risk is high when there is a lot of uncertainty about our chances to gain or lose something valuable. In the cargo supply chain several values are at stake, and this operations thus contain several types of risk. The material values and risks common to all participants are obvious: Keeping installations going and avoiding accidents. In addition there are potentially conflicting values: Installations that need supplies vs PSVs that judge it unsafe to deliver; installations that only need to consider their own situation vs PSVs that have to consider the entire schedule; and PSV crews that are fatigued and wish to seek shelter vs installations that wish them to stand by. On top of these 'material' values and risks are the social values and risks related to respect and reputation.

PSV operators must balance these "risk-mixes" in different ways in different situations, which means that they also face different kinds of 'trust-challenges' at different times. As they usually have very little information about the particular installation crew they are dealing with at any time they also have very little information about their trustworthiness. Trusting them is thus very risky, particularly with regards to the reputation they could give the PSV. In such situations PSVs face several dilemmas: They can maximise the material safety of installation, vessel, cargo and crew, or they can try to satisfy the installations' desire to receive cargo even though conditions are poor. Within this decision lies the other dilemma: The risk of being treated with disrespect, and to receive a bad reputation if they refuse to do what the installations want. Built into this latter conflict lies a potential material risk. If a PSV crew have too little information about the trustworthiness of an installation crew, the PSV crews may have to choose between the material risk of accidents and a potential loss of reputation.

FURTHER RESEARCH

The argument presented in this article is based on qualitative material. It shows that conflicting interests, complicated trust issues and concerns about reputation influences decisions and have the potential to decrease safety. My material does not, however, say anything about how frequently this happens or how this risk phenomena is distributed among PSV crews. Further quantitative research is therefore needed to investigate these matters.

REFERENCES

Allen, M. (2017). *The SAGE encyclopedia of communication research methods*. SAGE Publications.

Antonsen, S. (2009). The relationship between culture and safety on offshore supply vessels. *Safety Science*. 47(8), 1118-1128.

Antonsen, S., and Bye, R. (2015). "Vi" og "de andre". In S. a. K. Antonsen, T. (Ed.), *Sikkerhet i norske farvann*. Oslo: Gyldendal Norsk Forlag AS.

Ashleigh, M. J., & Stanton, N. A. (2001). Trust: Key elements in human supervisory control domains. *Cognition, Technology & Work*. 3(2), 92-100.

Barth, F. (1966). *Models of social organization*. Royal anthropological institute of Great Britain and Ireland.

Bauer, P. C. (2014). Conceptualizing and measuring trust and trustworthiness. *Political Concepts: Committee on Concepts and Methods Working Paper Series*. 61, 1-27.

Beck, U. (1992). From industrial society to the risk society: questions of survival, social structure and ecological enlightenment. *Theory, culture & society 9(1).* 97-123.

Bottema, H., Grol, E., Ladeur, V. and Post, K (2015). *Offshore Cargo Handling*. Rotterdam

Bourrier, M., & Bieder, C. (Eds.). (2013). *Trapping safety into rules: How desirable or avoidable is proceduralisation*, Boca Raton, FL, USA: CRC Press, Taylor & Francis Group.

Bulatova, J. (2015). The role of leadership in creation of organisational trust. *Journal of Business Management(9).*

Conchie, S. M., & Donald, I. J. (2006). The role of distrust in offshore safety performance. *Risk analysis, 26(5).* 1151-1159.

Cox, S., Jones, B., & Collinson, D. (2006). Trust relations in high-reliability organizations. *Risk analysis, 26*(5), 1123-1138.

Dekker, S. (2004). *Ten questions about human error: A new view of human factors and system safety*. CRC Press.

Deutsch, M. (1958). Trust and suspicion. *Journal of conflict resolution*. 2(4), 265-279.

Gausdal, A. H., & Makarova, J. (2017). Trust and safety onboard. *WMU Journal of Maritime Affairs, 16(2).* 197-217.

Gilbert, C., Amalberti, R., Laroche, H., & Paries, J. (2007). Errors and failures: towards a new safety paradigm. *Journal of Risk Research*. 10(7), 959-975.

Grimen, H. (2009). *Hva er tillit*. Universitetsforl.

Hassel, M., Utne, I. B., & Vinnem, J. E. (2014). *Analysis of the main challenges with the current risk model for collisions between ships and offshore installations on the Norwegian Continental Shelf.* Paper presented at the 12th International Probabilistic Safety Assessment and Management Conference, PSAM.

Holmström, S. (2007). Niklas Luhmann: Contingency, risk, trust and reflection. *Public Relations Review, 33(3).* 255-262.

International nuclear safety advisory group (1986). *Summary Report on the Post-accident Review Meeting on the Chernobyl Accident.* Vienna.

Jeffcott, S., Pidgeon, N., Weyman, A., & Walls, J. (2006). Risk, trust, and safety culture in UK train operating companies. *Risk analysis, 26(5),* 1105-1121.

Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.

Kongsvik, T., Bye, R., Fenstad, J., Gjøsund, G., Haavik, T., Olsen M. S., og Størkersen, K. V:. (2012). *Barrierer mot kollisjoner mellom fartøy og innretninger. Identifisering, vurderinger og* *mulige forbedringstiltak.* Studio Apertura, NTNU Samfunnsforskning.

Kvitrud, A. (2011). *Collisions between platforms and ships in Norway in the period 2001-2010*. Paper presented at the ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering.

Kvitrud, A. (2019). *Learning from dynamic positioning events*. Paper presented at the 38th International Conference on Ocean, Offshore & Arctic Engineering, Glasgow.

Kvitrud, A., Kleppestø, H., & Skilbrei, O. R. (2012). *Position incidents during offshore loading with shuttle tankers on the Norwegian Continental shelf 2000-2011*. Paper presented at the The Twenty-second International Offshore and Polar Engineering Conference.

Luhmann, N. (1979). *Trust and Power*. Chichester: Wiley.

Luhmann, N. (1988). Familiarity, Confidence, Trust: Problems and Alternatives. In D. Gambetta (Ed.), *Trust: Making and Breaking Cooperative Relations.* Cambridge, Massachusetts: Basil Blackwell.

Luria, G. (2010). The social aspects of safety management: Trust and safety climate. *Accident Analysis & Prevention, 42(4),* 1288-1295.

Mayer, R. C., Davis, J. H., & Schoorman, F. D. (1995). An integrative model of organizational trust. *Academy of management review, 20(3),* 709-734.

Möllering, G. (2001). The nature of trust: From Georg Simmel to a theory of expectation, interpretation and suspension. *Sociology, 35(2),* 403-420.

Morris, M. W., Leung, K., Ames, D., & Lickel, B. (1999). Views from inside and outside: Integrating emic and etic insights about culture and justice judgment. *Academy of management review, 24(4),* 781-796.

Norsok, S. N. a. (2017). *NORSOK standard. Sikker bruk av løfteutstyr.* Lysaker.

Okely, J. (2013). *Anthropological practice: Fieldwork and the ethnographic method*. Berg.

Pawelski, J. (2015). Safety of offshore supply operations. In A. Weintrit (Ed.), *Activities in Navigation: Marine Navigation and Safety of Sea Transportation.* CRC Press.

Perrow, C. (1984). *Normal accidents: Living with high risk systems.* New York: Basic Books.

Ptil. (2008). *Multi-national crane/lift autidts in the North Sea basin* [Press release]

Ptil. (2011). *Risiko for kollisjoner med besøkende fatøyer* [Press release]

Ptil. (undated). DFU7 - *Liste over kollisjoner (pp. A llist of Collisions between vessels and installations at the NCS between 1982 and 2015).*

Robben, A. C., & Sluka, J. A. (2012). *Ethnographic fieldwork: An anthropological reader*. John Wiley & Sons.

Røyrvik, J. (2012). *Værvinduet, en teknologisk artikulert entitet i oljeindustriens erobring av naturen.* (PhD thesis), NTNU, Trondheim.

Schoorman, F. D., Mayer, R. C., & Davis, J. H. (2007). An integrative model of organizational trust: Past, present, and future: *Academy of Management* Briarcliff Manor, NY 10510.

Seppänen, R., Blomqvist, K., & Sundqvist, S. (2007). Measuring inter-organizational trust—a critical review of the empirical research in 1990–2003. *Industrial marketing management, 36(2),* 249-265.

Solem, A., Kongsvik, T. and Anderssen, O. S. (undated). *Ti år med forbedret sikkerhet i Statoil Maritime operasjoner*. Retrieved from https://docplayer.me/4526449-Ti-ar-med-forbedret-sikkerhet-i-statoil-maritime-operasjoner.html

Sørhaug, T. (1996). *Om ledelse: makt og tillit i moderne organisering*. Universitetsforlaget Oslo.

Tvedt, E. F. (2014). *Risk modelling of collision between supply ships and oil-and gas installations*. Institutt for produksjons-og kvalitetsteknikk.

Whitehead, T. L. (2005). Basic classical ethnographic research methods. *Cultural ecology of health and change, 1,* 1-29.

Standard icons for function controls on navigation systems – design and issues

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Abstract - **Icons are graphical images used to represent processes or functions on the interfaces of electronic systems. Effective icons must be easily comprehensible for users. Within the maritime domain, icons used on navigation systems are subjected to technical requirements. However, there is no study investigating the comprehensibility of such standard icons. Face-to-face interviews and an online survey were conducted to evaluate standard icons specified in the performance standards. The results show issues with a number of standard icons prescribed in IEC 62288:2014. Specifically, icons from three groups: a) standard Panel Illumination and Display Brilliance icons have optional features that reduce icon concreteness, b) icons for display orientation modes lack specification for the Course Up mode and the proposed icon is not sufficiently distinctive, c) the standard icon for Radar Performance Monitor depicts a concept familiar to equipment manufacturers but unfamiliar to users.**

Keywords
Navigation systems, graphical user interface, icon design, usability.

INTRODUCTION

In electronic systems, icons are pictographic representations of functions and processes that support dialogues in human-computer interaction (Gittins, 1986).

The use of icons takes advantage of the capabilities of the human brain, which allows us to process imagery information faster and recognise previously-encountered images more accurately compared to words (Horton, 1993; Paivio, 2013). Additionally, icons take up less space than text commands - saving space for other display elements on the interfaces.

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Within the maritime field, icons are widely used in modern navigation systems such as Radar and Electronic Chart Display and Information Systems (ECDIS).

Despite the advantages, however, icons must be designed to convey the intended messages successfully. Studies on icon design have identified several icon characteristics to affect user performance and inadequate icons can be difficult for users to identify or locate (Ganor & Te'eni, 2016; McDougall, De Bruijn, & Curry, 2000).

In 2015, the International Maritime Organisation (IMO) started developing the Guidelines for the Standardisation of User Interface Design for Navigation Equipment, known unofficially as the S-mode Guidelines. The guidelines provide several regulations for the design of user interfaces for marine navigation systems, including a new set of standard icons for navigation functions and data. During the development process, the S-mode working group (hereby referred to as "the SWG") reviewed icons already in use for navigation systems as required by technical standards and found several them to be improperly designed.

This article discusses three cases of such inadequate icons, detailing design principles that those icons violate and the effects on users.

BACKGROUND

The development of the S-mode guidelines is a part of the IMO e-Navigation initiative, which regulates the future utilisation of information technology to improve safety and efficiency in shipping (IMO, 2008). The S-mode guidelines specifically target the design of user interfaces for navigation systems, aiming to improve usability and decrease diversity in the design of navigation equipment among different manufacturers (Jacobson & Lutzhoft, 2008).

To achieve its purposes, the S-mode guidelines standardise two features of navigational systems: terminology and symbology (icons), and the arrangement of information on the displays (IMO, 2018).

The new standard icons contained in the S-mode guidelines were developed following a human-centered design approach. The icons were subjected to tests and design iteration to ensure their usability.

At the time of developing the S-mode guidelines, many icons used on navigation systems were already regulated by technical performance standards, among which are the IEC 62288 standards for the presentation of navigation-related information on shipborne navigational displays, issued by the International Electrotechnical Commission [IEC] (2014). However, there was no official document on the development of such standard icons and there was no published research to demonstrate their usability. As a result, the SWG decided to include those icons in their tests.

Factors affecting icon usability

For an icon to be usable, it must be comprehensible to users. Studies in pictograph interpretation have found several factors that affect the comprehensibility of icons. Such factors can be separated into three categories, namely those that concern the design of the icon themselves, those that concern users, and the operational context.

Characteristics of individual icons include concreteness, complexity, and semantic distance. Additionally, icons are seldom presented in isolation, making distinctiveness an important characteristic.

Concreteness refers to the degree to which an icon resembles real objects, material, or people. Concrete icons are easier to interpret than abstract icon. Complexity refers to the number of visual details of an icon and has no effect on icon comprehensibility, but complex icons have negative effects on users' visual search performance. Semantic distance represents how closely an icon is related to the underlying concept and significantly affects the accuracy of icon interpretation among new users. For icon groups, a principle in icon design is minimising shared features between icons performing different functions while maximising shared features between icons of the same family (Kurniawan, 2000).

Regarding user characteristics, there are three factors affecting the ability to recognise icons; familiarity, domain knowledge, and cultural background.

Familiarity refers to the frequency of which users encounter an icon (Ng & Chan, 2008) or the frequency of which users encounter the object depicted in the icon (McDougall & Curry, 2004). Familiarity significantly improves the accuracy of icon interpretation (Shneiderman & Margono, 1987). Knowledge of the referent concept and cultural background also influences the interpretation of icons (Strauss & Zender, 2017; Zender & Cassedy, 2014).

Finally, context influences the interpretation of icons. The meaning of an icon is created by combining the icon image, the characteristics of the observer, and the context (Horton, 1994). However, for the tests discussed in this article, context was excluded due to complexity. Only icon and user characteristics were considered.

TEST METHODS

Two tests were carried out to assess icon usability. The first was face-to-face interviews with users and the second was an online survey.

Five master mariners took part in the interviews, three from India and two from Denmark. During the interviews, the icons were shown to each participant one by one, the first time without the associated labels and the second time with the labels. For each icon, the participant was provided basic context such as the equipment or the type of functionality and asked to interpret its meaning. The interviewer asked follow-up questions to explore the reasoning behind the interpretation. The participants were encouraged to provide additional comments regarding the design of the icons in question and suggest alternative icons if desired.

The online survey followed the reverse approach to the interviews. The survey showed participants a function and asked them to select among three available options the most suitable icon. Regardless of the answer, the survey would then reveal the meanings of all three icons, and participants could provide additional comments if desired. The number of respondents differs between questions, ranging from 27 to 45.

RESULTS AND DISCUSSION

A total of 59 icons were tested during the development of the S-mode guidelines. However, this article only discusses icons that were standard at the beginning of the S-mode development process.

The results show that many of those standard icons do not always convey their intended meanings. Those icons are regulated by IEC 62288 and belong to three function groups: setting up brightness level, setting up display orientation, and Radar performance monitoring.

The following sections present results and discuss issues with those icons.

Panel Illumination and Display Brilliance – the issue of concreteness

Panel Illumination and Display Brilliance are used to adjust brightness level for the control panel and the display screen respectively. IEC 62288 (IEC, 2014) provides standard icons for these two functions, as presented in Figure 1.

Figure 1. Panel Illumination and Display Brilliance icons

According to IEC 62388, both Display Brilliance and Panel Illumination icons have a circle surrounding the main symbol, and this circle is optional (IEC, 2014). We included these circles in all our tests.

In our first test (the interviews), four out of five participants associated the two icons Display Brilliance and Panel Illumination with the concept of brightness adjustment. However, the fifth participant could not make sense of the symbols. He commented that he recognised the main symbol but could not make sense of the surrounding circle and, therefore, could not identify the object being depicted.

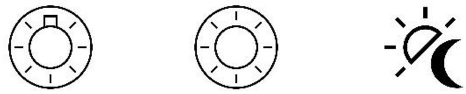
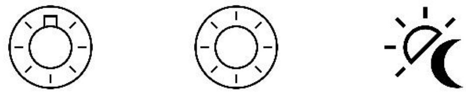
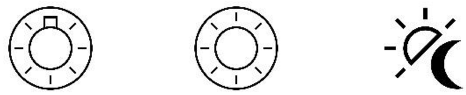
Results from the interviews raised the concern that the circle surrounding the main symbol in the two icons Display Brilliance and Panel Illumination could make the symbols less similar to real-life objects and reduce the concreteness of these two icons.

To further investigate if the circles were an issue, we proceeded with the second test using the online survey. In the survey, the icons Display Brilliance and Panel Illumination were compared to the icon for switching display colour combinations. This function is used to provide the best viewing in daytime, night time, and twilight, as presented in Figure 2:

Figure 2. Icon to select Day/Night/Twilight colour mode

Results of the survey are presented in Table 1

Table 1. Survey results for three icons Panel Illumination, Display Brilliance, and Day/Night colour modes (bold numbers highlight the most-selected option).

Which of the following Icons represents the function for setting Panel Illumination?		
		
10 (33%)	2 (7%)	**18 (60%)**
Which of the following Icons represents the function for setting Display Brilliance?		
		
9 (21%)	15 (35%)	**19 (44%)**
Which of the following Icons represents the function to toggle between Day/ Night/ display mode?		
		
2 (5%)	1 (3%)	**34 (92%)**

All three icons under discussion represent functions related to brightness/contrast adjustment and all three depict objects associated with the concept of light. Icon Panel Illumination resembles a lightbulb, icon Display Brilliance resembles the sun, and icon Day/Night resembles the sun and the moon. However, the Day/Night icon does not have a circle surrounding the main symbol.

Results from the survey clearly show that people are more likely to associate icon Day/Night with brightness adjustment than the other two. The circles in the two icons Display Brilliance and Panel Illumination caused the icons to be more abstract and reduce their comprehensibility.

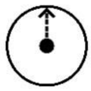
Display Orientation

There are three orientation modes for Radar; North Up, Head Up, and Course Up. The IEC 62288 provides standard symbols for the North Up and Head Up modes (IEC, 2014), presented in Figure 3:

Figure 3. Icons to select North Up and Head Up display orientation

There is no standard icon for the Course Up orientation. As a result, manufacturers are free to select an icon for this mode, which can lead to a lack of consistency between manufacturers and the potential use of inadequate icons. It is, therefore, necessary to develop a standard Course Up icon.

Using the principles in designing icon groups set out by Kurniawan (2000), the standard Course Up icon must share similar design features with the North Up and Head Up icons while maintaining sufficient distinctiveness. To address this matter, the Comité International Radio-Maritime (CIRM) proposed a standard icon for the Course Up orientation as presented in Figure 4.



Course Up

Figure 4. The proposed Course Up icon

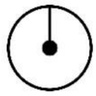
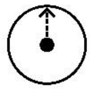
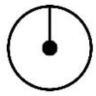
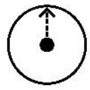
The SWG conducted tests to evaluate the suitability of this proposed icon.

In the first test (the interviews), one out of five participants correctly identified the Course Up icon. The other four participants interpreted the symbol as True Motion, Heading Line or Range.

The proposed Course Up icon uses a dotted arrow to depict the ship's course, and by having the line pointing up, the symbol refers to the Course Up orientation. However, based on feedback from the interviewees, these are also the features that confused them. The dotted line signifies motion, and in combination with the arrowhead, the dotted arrow was interpreted as the depiction of the ship moving forward, leading to the impression of True Motion. The dotted line was also interpreted as disappearing, and when combining with the arrowhead, the symbol was interpreted as the function to temporarily suppress the Heading Line. Additionally, the dotted line also signified distance measurement, causing one interviewee to interpret the icon as range measurement (Variable Range Marker). Results from the interview sessions indicate that the proposed Course Up icon did not clearly convey the message of Course Up orientation.

In the second test (the online survey), icon distinctiveness was evaluated. Results of the survey question are presented in Table 2.

Table 2. Survey results for three icons North Up, Head Up, and Course Up (bold numbers highlight the most-selected option).

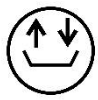
Which of the following Icons represents the function to select the <u>Head Up</u> orientation mode?		
		
6 (14%)	**20 (47%)**	17 (40%)
Which of the following Icons represents the function to select the <u>Course Up</u> orientation mode?		
		
0 (0%)	9 (31%)	**20 (69%)**

The survey results show that the proposed Course Up icon can easily be confused with the standard Head Up icon. The differences between the two are not significant enough to maintain satisfactory distinctiveness. Based on results from both the interviews and the survey, the proposed Course Up icon was not adopted into the S-mode guidelines.

Still, it is necessary to develop a standard Course Up icon to avoid diversity between manufactures. However, the SWG could not develop a suitable Course Up icon within the limited timeline. As a result, the SWG decided to use text labels instead of icons for all three orientation modes.

Performance Monitor

The IEC 62288 provides the standard icon for Radar Performance Monitor switch, see Figure 5.



Performance Monitor

Figure 5. Standard icon for Radar Performance Monitor

Performance Monitoring is a mandatory radar function that helps monitor and detects performance drop (IMO, 2004). This function works based on the following principle: the radar transmits a pulse to an object known as the echo box, mounted on a designed place onboard. This echo box is constructed and positioned in a way so that the energy re-radiated from it resembles returning radar signals from normal targets, despite its proximity to the radar receiver. The returning signal from echo box produces a visible response on the radar display, called performance monitor signal, and is used to monitor and detect any performance drop on the radar (Bole, Dineley, & Wall, 2005). Examples of such performance monitor signals on a Radar manufactured by Raytheon Anschutz (2014) are provided in Figure 6.

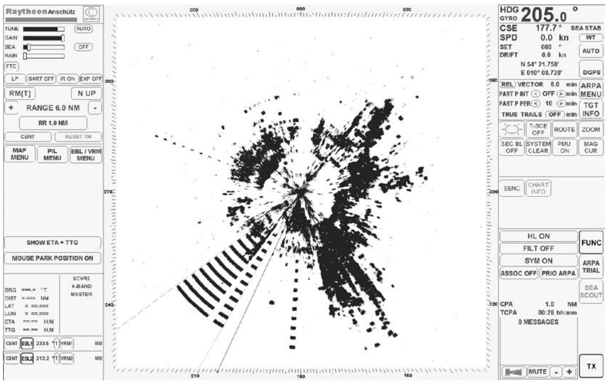


Figure 6. An example of performance monitor signals displayed on the Radar screen

In the interviews, none of the participants could recognise the icon as Performance Monitor. One participant commented that the symbol resembles a ship under rolling motion but could not understand the icon. The other four participants could not recognise the symbol. After the icon's meaning was revealed, all participants commented that the symbol has no visual cue to Performance Monitoring.

The icon did not perform well in the online survey either as 48% of the respondents did not correctly identify the Performance Monitor icon.

As mentioned in the Background, familiarity significantly affects icon interpretation. The standard icon as per IEC 62288 illustrates the working principle of the Performance Monitoring function. It depicts the transmitting and receiving of performance monitor signals from and to the antenna. Engineers who build and repair radars are familiar with this concept. To a seafarer, however, performance monitoring simply means observing and evaluating images of the Performance Monitor patterns displayed on the radar screen, as illustrated in Figure 6. The standard Performance Monitor icon has low comprehensibility because it depicts a concept unfamiliar to users.

While the SWG could not develop an alternative icon due to time constraint, the issue with this icon was forwarded to the IEC to be addressed in subsequent performance standards.

CONCLUSION

During the development of the Guidelines for the Standardisation of User Interface Design for Navigation Equipment (unofficially known as the S-mode Guidelines) as part of the IMO e-Navigation initiative, usability tests were conducted on standard icons used in navigation systems. The icons are specified in performance standards IEC 62288:2014. Issues were found in three icon groups that cause the icons to be difficult for users to interpret.

The icons for Panel Illumination and Display Brilliance have optional design features that reduce their concreteness and consequently their comprehensibility. It is, therefore, recommended that the circles be removed completely from the icons in the performance standards.

Icons for Display Orientation lack provision for the Course Up orientation, which can potentially lead to unnecessary design diversity. The proposed Course Up icon failed to maintain sufficient distinctiveness and, on its own, did not successfully convey the message of Course Up orientation. While the proposed icon was not adopted, the SWG could not develop a suitable alternative. Therefore, it was decided that text labels, instead of icons, would be used for all three Display Orientation modes.

Icon for Radar Performance Monitoring function depicts a process familiar to Radar manufacturers but unfamiliar to users. Consequently, many users cannot interpret the symbol. This issue was forwarded to the IEC to develop solutions in subsequent performance standards.

REFERENCES

Bole, A., Dineley, W., & Wall, A. (2005). *Radar and ARPA manual*. Oxford: Elsevier.

Ganor, N., & Te'eni, D. (2016). Designing Interfaces for Older Users: Effects of Icon Detail and Semantic Distance. *AIS Transactions on Human-Computer Interaction*, *8*(1), 22-38.

Gittins, D. (1986). Icon-based human-computer interaction. *International Journal of Man-Machine Studies*, *24*(6), 519-543.

Horton, W. (1993). Figures of image: Aristotle and the design of icons and hypermedia. *Technical Communication*, *40*(3), 495-500.

Horton, W. (1994). *The icon book: Visual symbols for computer systems and documentation*. New York, NY: John Wiley & Sons, Inc.

IEC. (2014). *IEC 62288:2014 - Maritime navigation and radiocommunication equipment and systems - Presentation of navigation-related information on shipborne navigational displays - General requirements, methods of testing and required test results*. International Electrotechnical Commission

IMO. (2004). *MSC.192(79) - Adoption of The Revised Performance Standards for Radar Equipment*. International Maritime Organisation

IMO. (2008). *MSC 85/26/Add.1 - Strategy for the development and implementation of e-Navigation*. International Maritime Organisation

IMO. (2018). *NCSR 6/7 - Guidelines on standardiesd modes of operation, S-mode - Report of the Correspondence Group*. International Maritime Organisation

Jacobson, E., & Lutzhoft, M. (2008). *Developing user needs for S-mode*. Paper presented at the International Navigation Conference, Church House, Westminster, London.

Kurniawan, S. H. (2000). *A rule of thumb of icons' visual distinctiveness.* Paper presented at the Proceedings on the 2000 conference on Universal Usability.

McDougall, S., & Curry, M. (2004). *More than just a picture: Icon interpretation in context.* Paper presented at the Proceedings of First International Workshop on Coping with Complexity. University of Bath.

McDougall, S., De Bruijn, O., & Curry, M. (2000). Exploring the effects of icon characteristics on user performance: The role of icon concreteness, complexity, and distinctiveness. *Journal of experimental psychology. Applied, 6*(4), 291-306.

Ng, A. W., & Chan, A. H. (2008). *Visual and cognitive features on icon effectiveness.* Paper presented at the Proceedings of the international multiconference of engineers and computer scientists.

Paivio, A. (2013). *Imagery and verbal processes*: Psychology Press.

Raytheon Anschutz. (2014). *Synapsis Radar Operator Manual*. Kiel, Germany: Raytheon Anschütz GmbH.

Shneiderman, B., & Margono, S. (1987). *A Study of File Manipulation by Novices Using Commands vs. Direct Manipulation.* Paper presented at the Proceedings of 26th Annual Technical Symposium of the Washington, DC.

Strauss, A., & Zender, M. (2017). Design by Consensus: A New Method for Designing Effective Pictograms. *Visible Language, 51*(2), 6-33.

Zender, M., & Cassedy, A. (2014). (mis)understanding: icon comprehension in different cultural contexts. *Visible Language, 48*(1), 68-95.

Opportunities and Challenges in Using Ship-Bridge Simulators in Maritime Research

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Abstract - **Ocean industry prospects are addressing core challenges such as food, security, energy and climate change. The ocean holds the promise of great potential for economic growth. Appropriate tools are required for answering the questions of the emerging ocean operations. Questions related to technology development, training, safety and efficiency rise on daily basis. Ship-bridge simulators are ideal arenas for research and innovation. Simulators are used in maritime contexts, mainly in education and training. However not much is published regarding the use of simulators in maritime research. This paper presents a literature review of the use of simulators in maritime research in the recent years. Additionally, it highlights the opportunities and challenges of using simulators in the maritime industry according to interviews held with academics and professionals in the field, in Norway and abroad.**

Keywords

Ship simulators, research, opportunities and challenges, training, the future of shipping.

INTRODUCTION

What is a simulation? What is a simulator?

Replication, duplication and projection of reality are three faces of simulation. Role-play, maps, and computers are possible tools for running simulations. Computer simulations are powerful tools to study complex systems and have wide variety of applications in engineering, science, medicine, economics and social sciences. A computer simulation, in its narrowest sense, is a computer program that follows step-by-step instructions to approximate the state of the system being described by the instructions. The algorithm takes as input the initial values (the values of all of its variables at time t equals to zero). Then it calculates the system's state (the variables of interest) at the first time step.

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From the values of the state at the first time step it calculates the state at the second time step, and so on the computer simulation progresses the calculations with time. The results of the computer simulation can be visualized and compared to results obtained from a scientific instrument that measures the system's state.

According to Winsberg (2003): "Successful simulation studies do more than compute numbers. They make use of a variety of techniques to draw inferences from these numbers. Simulations make creative use of calculational techniques that can only be motivated extra-mathematically and extra-theoretically. As such, unlike simple computations that can be carried out on a computer, the results of simulations are not automatically reliable. Much effort and expertise goes into deciding which simulation results are reliable and which are not."

Simulations are generally used for estimation of system states (prediction of data that we do not have) or generating understanding of data that we do already have. In the case of ship motion, the simulation accounts for hydrodynamics seakeeping and maneuvering theories in finding the progress of motions in the desired degrees of freedom. Mathematical equations based on those theories are at the core of the simulation. It also accounts for environmental loads as stochastic processes that keep on changing with time. The loads from winds, waves and currents are fed, at every time step, into the mathematical equations and influence the resultant force. The force that affects the direction and magnitude of the motion of the ship. Still, the motion of the ship can be controlled by, for example, rudder and thruster human inputs. Such control inputs can also be incorporated, otherwise be set as predefined states, depending on the goals and objectives of the simulation.

A computer simulation is normally run on a desktop computer and the results are processed and visualized, mainly in graphs, after the calculation is over. Whereas, a simulator is a real time computer simulation that looks and feels like reality, it is "a piece of equipment that is designed to represent real conditions, for example in an aircraft or spacecraft: people learning to fly often practice on a flight simulator." (Cambridge University Press, 2018).

Simulator is interactive, with human in the loop, such as in a flight simulator, sailing simulator or a driving simulator. It is "a device that enables the operator to reproduce or represent under test conditions phenomena likely to occur in actual performance" (Merriam-Webster, 2016).

Industry trends regarding the use of simulators

Use of simulators, either for entertainment or for training, is increasing. Nowadays there are off-the-shelf bicycle simulators and golf simulators for customers that want to practice at home. Apart from personal-use simulators, the use of simulators in the industry is expanding. The healthcare industry is using medical simulators to teach therapeutic and diagnostic procedures. The automotive industry is using truck simulators to provide beginners adequate training. CARLA is an open source simulator for autonomous driving research to support development, training and validation of autonomous urban driving systems (Dosovitskiy *et al*, 2017). The racing industry is using racing simulators to train professional racers maintain their skill and sharpness. The chemical industry is using operator-training simulators to create a safe and realistic virtual environment to train engineers for safer operations in process plants. In the space industry, shuttle grounds operations simulator is used to debug and verify the functionality of space application software of the international space station. Ending the examples with the maritime industry, ship-bridge simulators, remotely operated underwater vehicles (ROV) simulators and crane simulators are used together for advanced offshore operations planning.

Trends regarding use of simulators in training and education

Ship-bridge simulator-based training practice is well established in maritime education. The International Convention on Standards of Training, Certification and Watchkeeping of Seafarers (STCW) of the International Maritime Organization (IMO) regulates the standards of training. The main purpose of the Convention is to promote safety of life and property at sea and the protection of the marine environment to ensure that future professional mariners can operate properly and safely in their work practice, this convention emphasizes on the use of simulators for both training and assessment.

The set of simulator-based training courses offered by IMO, for both the novice and the experienced participants includes:

- *Ship simulator and bridge teamwork course;*
- *Liquefied petroleum gas (LPG) tanker cargo & ballast handling simulator course;*
- *Liquefied natural gas (LNG) tanker cargo & ballast handling simulator course;*
- *Chemical tanker cargo & ballast handling simulator course;*
- *Oil tanker cargo and ballast handling simulator course;*
- *Automatic Identification System (AIS) course; and*
- *Train the simulator trainer and assessor course.*

In June 2015, after a series of EU projects from 2009, the IMO approved a "Guideline on Software Quality Assurance and Human-Centred Design (HCD) for e-Navigation". The objective of e-Navigation concept is to harmonize the collection, integration, exchange, presentation and analysis of marine information by electronic means to enhance the operations and their safety. IMO considers that e-Navigation should be user driven rather than technology driven. HCD methods require heavy involvements of seafarers and operators in the design and development process of navigation aid tools. From 2015, the IMO recommends that HCD should be used in development of new navigation equipment (IMO, 2015).

Maritime simulators are classified into four classes based on their capabilities. Class A (full mission); Class B (multi-task); Class C (limited task); and Class S (special task) is used when the performance is defined on a case by case basis (Det Norske Veritas, 2011). Different types of maritime simulators exist, related to the operation they replicate, for example:

- Bridge operation simulator;
- Machinery operation simulator;
- Radio communication simulation;
- Cargo handling simulator;
- Dynamic positioning (DP) simulator;
- Safety and security simulator;
- Vessel traffic services (VTS) simulator;
- Survival craft and rescue boat operations simulator;
- Offshore crane operation simulator; and
- Remotely operated vehicles (ROV) operation simulator.

This article is about the use of ship-bridge simulators in research, this includes simulator Classes A & B, and bridge operation and dynamic positioning simulator types. Other names are also used to describe them such as full-mission simulators and ship handling simulators. In this article, the simulators of interest are ship-bridge simulators. From now on the term "simulators" is used to refer to ship-bridge simulators. As described by Porathe (2016) "A ship-bridge simulator is a piece of laboratory hardware and software that simulates a ship's behavior from the vintage point of its bridge.

Often 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".

While lately, the demand in using simulators is increasing and the purposes of using simulators are branching into specific niches. Simulators are not only used for training, they are also being lately used in research. This paper tries to answer the following questions:

1. What are simulators currently used for in research?
2. What are the opportunities of using simulators in research?
3. What are the challenges of using simulators in research?

METHODOLOGY

In order to answer the three questions above, two main methods have been used. First is a literature review for relevant research that uses simulators, second is interviews with professionals and researchers in the field. Details about the two methods follow.

Method I – The literature review is made to contribute mainly in answering the first question: "What are simulators used for in research?" A literature search in the search engine "Oria" of the Norwegian University of Science and Technology (NTNU) that provides search of the university's both printed and electronic collections of internationally renowned scientific databases (and publishers) such as INSPEC (Journal of Navigation), Scopus (Elsevier, Springer, IEEE), ProQuest, Transnav and WMU. Search criteria of the literature review are as follows:

Table 1: Literature review search criteria

Keywords:	Ship simulator; bridge simulator; mission simulator
Publication date:	Last 10 years
Material type:	Articles and journals
Other filters:	The publications that do not involve use of simulator are filtered out
Number:	50 publications

Method II – Interviews were held to bring a variety of perspectives from both researchers and professionals in the field. A google search was made for both academic and commercial simulator centers all over the world. Thirty-five centers were found. A shortlist of contacts for interview invitations was created that includes the following three groups:

Group i. Six internal researchers (employed by NTNU) that have performed experiments in simulators.

Group ii. Sixteen external researches (employed by other institutions around the world) that were first authors of publications found in the literature review.

Group iii. Twelve managers at research centers.

The shortlisted people were invited to interviews. Ten positive responses were received and actually nine interviews were performed: four from the first group; one from the second group; and four from the third group. The interview questions were the same for all of the interviewed persons. A little bit of customization was included in the introduction of the interviews to fit with every person's background and current works. The interview questions are:

Question i. Tell us about yourself and the field of your interest.

Question ii. What opportunities do you think simulators provide for research (/ or for the industry)?

Question iii. What challenges you faced during using simulators for your research (/or for your work)?

The general semi-structured open-ended questions helped in outlining the interview conversation. They were half-an-hour interviews that started with an introduction about the authors of this article and their motivation for writing it. This paper utilized inductive coding method for analyzing data from interviews.

LITERATURE REVIEW

Fifty publication were found based on the search criteria. The publications are classified into three categories. The first category is "Simulator Facility" and this concerns publications that focus on the simulator facility itself, they provide proposals of software and hardware developments, including algorithms and models. The second category is "Experimental Practice" and this concerns publications that provide knowledge about the practice of performing experiment in the simulator, this includes instructor roles, hierarchies and social structures. The third category is "Training and Evaluation" and this concerns publications that report on methods for performance monitoring of navigators, including evaluations of teamwork and training for specific operations. The Venn diagram of the classification is shown in Figure 1.

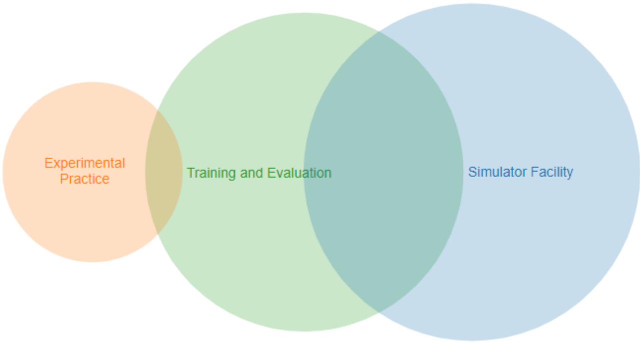

Figure 1: Venn diagram of the literature classification. Created by the online tool https://www.meta-chart.com/venn

The publications of the *Simulator Facility* category are split into five sub-classifications as presented in Table 2. The table provides a sample of publication names and lists the remaining references for each sub-classification. Table 2 is found in the Appendix.

The *Evaluation of technology* sub-classification includes publications that investigates technologies such as visual system; advanced decision support systems; direct gesture interaction methods; and accuracy of hydrodynamic methods.

The *Software for autonomous capability* sub-classification includes publications that propose algorithms and models for autonomous maneuvering; intelligent target ships maneuvering; communication and intention exchange; and safety quantification. One publication presents the capability of generating real-time objects in a simulator based on Automatic Identification System (AIS) data (Last, Kroker, & Linsen, 2017).

The *Software for fuel and emissions* sub-classification includes publications that investigate the relationship between maneuvering and fuel efficiency or emissions. Such research do not only provide knowledge, also provides models that can be incorporated in a simulator to extend its usage.

The *Software for human evaluation* sub-classification is a subset of the *Training and Evaluation* category. It includes methods and algorithms for quantifying human interactions; performance; non-technical skills and mental workload.

The *Software for specific operation* sub-classification includes publications that presents software additions to simulators to enable simulations of specific operations such as icebreaker escort; restricted waters maneuvering; ship-to-ship lightering and shallow waters maneuvering with attention to ship squat.

The publications of the *Experimental Practice* category are split into two sub-classifications as presented in Table 3. Table 3 is found in the Appendix.

The *Safety training* sub-classification includes publications presenting simulator experimental practices for ship Bridge Resource Management training; simulating marine collisions leading to a safer operating future, and benefits for safety training and investigation.

The *Pedagogical approach* sub-classification includes publications that provide analysis and assessment of the training activity. They focus on the learning component and the actions of instructors.

The publications of the *Training and Evaluation* category are split into three sub-classifications as presented in Table 4. Table 4 is found in the Appendix.

The *Evaluation of training technology* sub-classification includes publications that examine the effect of technology advancements on human performance.

The *Performance evaluation* sub-classification includes publications that study the human performance. Most of them study the human performance quantitatively using physiological measurements. Quantification efforts of the following are apparent: workload; human interactions; mental stress and strain; and teamwork.

The *Technology on Training* sub-classification includes innovative methods for training for specific operations. Training such as emergency unberthing without tug assistance and training for energy-efficient maneuvering. Additionally, it includes methods for quantifying training evaluation, such as the proposal of an evaluation index for berthing operations.

The literature shows two main paths and one emerging path of simulator research. The first main path evolves around the capability of the simulator facility. On the one hand, investigating the current capabilities, such as the accuracy of hydrodynamic models. On the other hand, developing models that enable new capabilities such as simulating ship-to-ship lightering operations. The second main path evolves around the use of simulators for training and evaluation. This path investigates and utilizes technology for training. In addition, this path focuses on quantification, providing methods for performance evaluation in a quantitative manner. Finally, the emerging path is investigating "how to make the most of simulator training by understanding the practice?" this path mainly concerns the simulator instructors. Next section is the presentation of the second method, the interviews.

INTERVIEWS

Nine interviews were held. Conversations about usage, opportunities and challenges of simulators were coded and analyzed. The interview findings are listed in Table 5. The next section, Discussions, includes two parts, the analysis of the interviews, and the discussions based on the two methods. Table 5 is found in the Appendix.

The interviewees have different backgrounds, seven of them have engineering background and two have social science background. The main usage of simulators according to the interviews is related to education and training. However, interesting applications are emerging such as sensor fusion of physiological data and testing technology and algorithms towards autonomous operations.

The opportunities are summarized in three main points. First, simulators are facilitators of research and innovation. Second, simulators stimulate change in industry workflows. Third, simulators open new frontiers towards transforming the industry.

All the researchers have agreed on the research infrastructure challenges. Such as the availability of simulators and availability of some expert helping hand to aid them throughout their experiments. While the managers mentioned issues related to cost of handling and maintaining simulator facilities. Analysis, interpretations and discussions follow in the next section.

DISCUSSIONS

In the light of data from both the literature review and the interviews, the three areas (usage, opportunities and challenges) are discussed in this section. The literature review data provided relevant and up-to-date knowledge regarding research using simulators. The authors have very different backgrounds, in fact, the majority of researchers are not from nautical science disciplines. However, in interviews, researchers emphasized the challenge of needing some expert help to aid them throughout the experiments. Since the nautical science education in not taking precedence over the research in ship-bridge simulators, then a gap and a need in maritime research activity is identified. Filling such a gap will shape the future of shipping. Especially that simulators are embracing multi-disciplinarity and bringing human and technology in the loop. Domain education and expertise are worth to be brought in the loop as well.

Usage

It is promising to see this spectrum of research disciplines running simulator experiments in the last ten years. However, the use of simulators in research is limited to researchers with access to simulators. This privilege is not available to many researchers around the world. Taking into consideration the trend of increased demands and increased usage of simulators in the past years. Keeping in mind that the opportunity list is very seducing for both the academy and the industry to pursue simulator research for shaping a safer and a more efficient future for the maritime industry. Given these inputs, I think it is probable that the demand on simulator facilities will rise significantly in the next ten years and thus the usage of simulators in research will. The accessibility is a limiting factor in the growth of simulator research, however, technology advancements could provide solutions, such as virtual reality (VR) simulator technology.

The usage of simulators today, other than simulator-based education and training, is summarized as research towards education and towards developing technologies. It is interesting to harvest the fruits of the technology research part. Then, it is expected, quite soon, to see simulator usage embedded in industry processes such as ship design, port design, controllers design and the like. Such processes complement and support human-centred design frameworks that are essential methods for designing safety-critical systems and are recommended by the IMO. The next section is an analysis and discussion of the opportunities.

Opportunities

This section summarizes the opportunities of broadening the use of simulators. Simulators offer important proof of concept capability to innovations in ship-bridge design, port design and research ideas. Simulators are a haven for human factors and sociocultural diversity research. Nevertheless, the research and development of autonomous vessels will depend largely on simulator experiments. Starting with a brief about simulator advantages to lay the foundation for the opportunities.

Advantages

The advantages of simulators are massive, and here are several of them. First, simulators bring human-in-the-loop. The human user in the simulator is a central element of the performed operation. For the case of ship-bridge simulators, the human is the one observing, perceiving and interacting with the navigation equipment to achieve the desired maneuvers. Second, in the same manner, simulators bring the hardware in the loop as well. Real and up to date hardware is required to be installed in the simulator for delivering the expected experience of realism. This requirement is valid for all interaction hardware, such as rudder and thruster controllers, seat, cabin / bridge furniture, radar screen and so on.

Third, simulators provide full control of the situation. A simulator is a safe lab to practice risky operations in harsh conditions. Fourth is feasibility. Running a demanding operation in a simulator is certainly dramatically more feasible than actually executing the operation itself. Instead of simulating the complete actual operation, concentrated chunks can be simulated to investigate or train the users for particular skill, thus saving time and resources. Fifth is Flexibility. The simulators offer flexibility in setting winds, waves and currents loads. In addition, it also offers flexibility in setting scenarios, the traffic, time, day and night, and so on. However, the flexibility is limited to designed flexibility. For instance, if the researcher requires enhancing the level of autonomy for the target ships, this cannot be done without further programming and software development.

Sixth, simulators run in real time, some of them have a capability in running faster than real time, and this property opens prediction and augmentation opportunities. Seventh simulator operations are reproducible. This is key property for research. The researcher is able to reproduce the conditions and perform the experiment over and over again.

And finally, simulators open new frontiers. They can simulate operations in very harsh and very rare weather conditions. They even can simulate cases not possible in real life. Such as planning iceberg management or optimization of seismic survey ship scan routes. A simulator center in Canada has developed a dynamic positioning (DP) controller for the arctic waters that accounts for wind, waves, currents and snow forces. A simulator center in Norway identified that seismic ship operators navigate differently and is investigating the optimal route for seismic survey navigation.

Proof of concept

Simulator runs come handy in the ability to validate or refute concepts regarding ship and port design. Not only valuable for proof of concept, but also for further developments and training. According to an interviewee, simulator runs can be used to train people, algorithms and procedures. Simulator experiments are crucial in the development of the following disciplines. First, research ideas can be validated in a simulator. For example, a researcher with own hypothesis: “separated traffic schemes will enhance safety in the sea” can structure simulator experiments to investigate the very existence of a relationship between the variables of interest. Second, algorithms can be trained in simulators and by simulators. Artificial intelligence algorithms require learning datasets. Datasets that teach the algorithm how things work in certain conditions. Simulators can provide valuable learning datasets for such algorithms. Then, the performance of the trained algorithm can be put under investigation in another simulator experiment.

Third is hardware. That is a two-folded opportunity. From the one hand, simulator experiments are used to verify and validate the performance of a piece of hardware, whether it delivers the actions as expected. From the other hand, an interviewee mentioned that learning curves of novice and experienced users could be investigated to evaluate the easiness and user-friendliness of the piece. Fourth, simulators are fit for purpose for evaluating new port designs. Pilots can run trials into and out of the port in a simulator with different ship sizes and test geometrical port features. Fifth, the use of simulators early on in the process of ship design. From maneuvering capabilities to bridge technologies, all can be investigated with operator in the loop in the simulator. Finally, simulators are the place to risk-free test interaction methods. Interface items such as controllers, visuals and bridge layout are subject to testing in a simulator for evaluating the impact of the changes on the performance of seafarer subjects.

Human factors

Simulators bring the opportunity to investigate group dynamics and interactions in a maritime operation setting. According to an interviewee, sociocultural variables could be considered and investigated in research such as gender differences, cultural differences, experience, and age differences. I think that “teamwork in critical operations” is a field that will benefit a lot from simulator capabilities. Simulator experiments also make observing the experts possible. An important data source for designers to learn how do experts really use and interact with the machine.

Development of methods

According to an interviewee, simulator involvement in the process of ship design for example is disrupting the industry practices and workflows. In line with HCD philosophy, the simulator becomes a regular meeting point among the designer, the owner, and the operator. I see that simulators can bring integrated operator’s experience and owner’s desires and constraints into the design process early on. This provides transparent exposure and understanding among project partners. Creating a paradigm shift in industry practices.

Another perspective for looking at this point is that simulator experiments reveal knowledge that was not known before, this knowledge is used as a convincing tool to persuade the industry rethink their methods and practices.

Autonomous vessels

While investigating the safety and efficiency of different levels of autonomy, I think that simulators are the best havens for running numbers of scenarios and cases with all kinds of traffic mixtures involving autonomous vessels, remotely controlled ships, and conventionally-controlled commercial vessels including leisure boats and small fishing boats. The accumulated digital nautical miles provide experience and knowledge preparing the industry to take assured steps forwards. Simulators can also be the lab for testing guidance, navigation and control (GNC) algorithms.

Virtual ocean

As the numbers of simulators increase and their demand increases as well. I see that there is an opportunity of connecting simulator centers together and creating a digital model of the world's oceans, including coastlines and ports. Calling it the *Virtual connected ocean*, a shared ocean space for all kinds of ocean economy related research. Simulator centers can access the shared space and perform operations for research, training and technology development.

Anywise, when linking the current usages with the opportunities, then the imagination and the processing power are the limits of what a simulator can do. In other words, I believe that the scope of simulator usage is expected to grow significantly in the future. The next section is an analysis and discussion of the challenges.

Challenges

Simulators are technology driven. They advance together with technology advancements in computer processing power, graphics and visual systems and real-time hydrodynamic models. Despite of the state of the art, technologies do have their pitfalls occasionally. The challenges based on the experiences of the interviewed experts are summarized in this section. Part of the challenges is practical and is related to the setup, equipment, participants, and etc. The other part is philosophical, and is attached to the fact that a simulator is a simulator and reality is something else. Ironically, the philosophical challenges are closely related to the advantages of simulators.

Availability

The main challenge is availability. Simulators are physical rooms and there are some requirements need to be met before an experiment is ready to be held. According to interviewees, the challenge of the availability of the following was mentioned. First, the availability of simulators facilities. Researchers need to wait elongated periods sometimes in order to have a time slot for their simulator experiments. Second, the availability of experienced participants. It is not simple to book experienced seafarers for simulator experiments. They are not always available.

Third, the availability of technical support. An expert technician is required to help the researcher manage the data flows and logging. Additionally, to implement modifications on simulation configuration including scenario location, target ships, traffic, time, weather, equipment functionalities, and so on. Fourth and last, the availability of up-to-date interaction hardware is a challenge. Maintaining the feeling of the experience as realistic as possible, the full-scale up-to-date hardware is required to be installed, calibrated and connected in the simulator and be ready for use.

Data management

Big data volumes can be collected from a simulator experiment. Research infrastructure is required to enable researchers collect the data they seek otherwise it is very challenging to setup and achieve the desired data collection. Multiple possible data sources are there, and here are some examples. First, the ship data. This is mainly the data of the simulation software that holds quantitative information about the locations and motions of the ship(s) (i.e. location coordinates, course, heading, speeds, roll, pitch and other motions as they progress with time). Second, the navigation aids data, this include Radar images, ECDIS and AIS data. Third, the human-machine communication data, which is the record of all human control, inputs including thruster, rudder and other instructions.

Fourth, the human-human communication data. Whether it is communication among the bridge team, or communication between the bridge and others vessels, instructors or VTS. Fifth, physiological sensor data. This includes data from eye-trackers, heart-rate sensors, Electrocardiography (ECG), Electroencephalography (EEG), Electromyography (EMG), respiration sensors and temperature sensors. Note that wearing the physiological sensors on the body and keeping the wires connected is not only challenging, also heavy and motion restricting, thus the participant will be limited in motion and not feeling comfortable. Lastly, video data. Video recordings of the simulator session includes the bridges and instructor rooms brings valuable data for education and collaboration research fields.

Realistic physics and underlying assumptions

With the real-time constraint, the accuracy of the physics is not guaranteed in a simulation. The hydrodynamic models at the core of the simulator software have underlying assumptions. In some conditions where such assumptions are physically invalid, the uncertainty in the computed ship response becomes high, thus, the simulator experience becomes less realistic. Unless, specialized hydrodynamic models where created and validated. Few examples of less realistic simulator experiences:

i. The last meter in a docking operation: as the ship is approaching into a dock, the behavior of the ship in the simulator gets less realistic. This is also true with approaching to any structure, such as ship-to-ship operations or sailing in a tunnel.
ii. Co-simulation: for example, the co-simulation of an offshore crane operation, the crane is mounted on the ship. The ship is moving in waves, the crane is lifting a load; the motion of the ship is affecting the motion of the lifted load and vice versa. The motion coupling is a non-trivial problem to solve. Therefore, the simulator experience deviates from the real world.
iii. Shallow water navigation effects are not appreciated in a simulator, because one of the underlying hydrodynamic assumptions is that the ship is sailing in deep water. However, there have been development of shallow water hydrodynamic models lately to cover this gap.

Software is software

Simulators, like other software, might have periodic problems, bugs and shutdown problems every now and then. According to interviewees, one expert technician per facility is required to maintain the simulators and perform both corrective and preventive maintenance measures. System updates increase the realistic functionality and feel, however it is typical, with every update, there is something lost that requires troubleshooting and fixing. The maintenance of a simulator facility is costly.

Philosophical challenges

A simulator experiment is not a real-life operation, yet, we desire them to be identical. The philosophical challenges are rooted from the differences of real-life operation conditions and simulator exercise conditions. For instance, the duration of the operation in real-life is long. It includes the trip to the location, the operation and the trip back, in which the operators live onboard. However, in simulator exercises, the participants would have a much shorter exercise, after which they can go home to relax and then have comfortable sleep. Real-life operators work longer shifts and they sleep with the ship motions, and would develop feelings of isolation. The duration, location, motions, seriousness and the overall feelings and thoughts of the operator would be different. This difference is related to the difficult question of validity and reliability of simulator experiments.

Discrepancies in results

In the literature review, one finding is the clear lack of published articles by authors with nautical science backgrounds. The nautical sciences are a new scientific tradition, very grounded in work and experience, while technologies are advancing fast and their involvement, as nautical scientists, in research and innovation is crucial for preparing the industry towards a better a future.

In the interviews there were no disagreements found, therefore, just the main agreements are highlighted. Regarding opportunities, 8 out of 9 mentioned statements that mean “simulators are tools for technology advancements such as the development of autonomous ships”. 5 out of 9 referred to simulators as good places for human factors research. 4 out 9 referred to simulators as enablers for developing processes, such as industry practices. Regarding challenges, 6 out of 9, expressed the urge of availability of expert help during simulator exercise. Help with managing the data and configuring the simulators is described as “indispensable”. 3 out of 9 agreed that achieving the realistic feel of the operator’s experience is quite challenging in a simulator.

CONCLUSIONS

Motives supporting the use of ship-bridge simulators in research, and thereafter, in the industry could be safety, efficiency and developing current technologies. A substantial share of the research work can be done in simulators, hence, simulators can be described as the safe havens and feasible laboratories for maritime research. They open new frontiers of research and development. Not only development of products and algorithms, but also the development of mindsets. Simulators gather people and gather disciplines together. Industry practices in design, for instance ship design, could change as a result of simulator research benefits. The IMO, since 2015, is recommending human-centred design approach in industry practices. This was a tangible result of simulator research. Simulators offer researchers multidisciplinary exposure, with engineer, seafarer, hardware and software in the loop. However, a gap in research is identified where the nautical domain education and expertise are needed and are encouraged to follow up.

The main opportunity for using ship-bridge simulators in research is the integration in the development processes of new technologies and designs. Whereas, the main challenge is the need of research infrastructure that includes technical support and appropriate tools for observation, collection and management of data.

REFERENCES

Arenius, M., Athanassiou, G., & Sträter, O. (2010). Systemic assessment of the effect of mental stress and strain on performance in a maritime ship-handling simulator. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *11*(PART 1). https://doi.org/10.3182/20100831-4-FR-2021.00009

Ari, I., Aksakalli, V., Aydoğdu, V., & Kum, S. (2013). Optimal ship navigation with safety distance and realistic turn constraints. *European Journal of Operational Research*, *229*(3), 707–717. https://doi.org/10.1016/j.ejor.2013.03.022

Benedict, K., Kirchhoff, M., Gluch, M., Fischer, S., Schaub, M., Baldauf, M., & Klaes, S. (2014). Simulation Augmented Manoeuvring Design and Monitoring: a New Method for Advanced Ship Handling. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *8*(1), 131–141. https://doi.org/10.12716/1001.08.01.15

Bjørneseth, F. B., Dunlop, M. D., & Hornecker, E. (2012). Assessing the effectiveness of direct gesture interaction for a safety critical maritime application. *International Journal of Human Computer Studies*, *70*(10), 729–745. https://doi.org/10.1016/j.ijhcs.2012.06.001

Cambridge University Press. (2018). *The Cambridge Dictionary*. *Cambridge University Press*.

Christensen, K., Kleppe, G., Vold, M., & Frette, V. (2014). Quantitative projections of a quality measure: Performance of a complex task. *Physica A: Statistical Mechanics and Its Applications*, *415*, 503–513. https://doi.org/10.1016/j.physa.2014.06.068

Cohen, I., Brinkman, W. P., & Neerincx, M. A. (2015). Modelling environmental and cognitive factors to predict performance in a stressful training scenario on a naval ship simulator. *Cognition, Technology and Work*, *17*(4), 503–519. https://doi.org/10.1007/s10111-015-0325-3

De Souza, J. R., Tannuri, E. A., Oshiro, A. T., & Morishita, H. M. (2009). Development and application of a ship manoeuvring digital simulator for restricted waters. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*. https://doi.org/10.3182/20090916-3-BR-3001.0071

Det Norske Veritas. (2011). Standard for certifcation No. 2.14 Maritime Simulator System, (2).

Dosovitskiy, A., Ros, G., Codevilla, F., Lopez, A., & Koltun, V. (2017). CARLA: An Open Urban Driving Simulator, (CoRL), 1–16. Retrieved from http://arxiv.org/abs/1711.03938

Formela, K., Gil, M., & Sniegocki, H. (2015). Comparison of the Efficiency of Williamson and Anderson Turn Manoeuvre. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *9*(4), 565–569. https://doi.org/10.12716/1001.09.04.14

Håvold, J. I., Nistad, S., Skiri, A., & Odegård, A. (2015). The human factor and simulator training for offshore anchor handling operators. *Safety Science*, *75*, 136–145. https://doi.org/10.1016/j.ssci.2015.02.001

Hontvedt, M. (2015). Professional vision in simulated environments - Examining professional maritime pilots' performance of work tasks in a full-mission ship simulator. *Learning, Culture and Social Interaction*, *7*, 71–84. https://doi.org/10.1016/j.lcsi.2015.07.003

Hontvedt, M., & Arnseth, H. C. (2013). On the bridge to learn: Analysing the social organization of nautical instruction in a ship simulator. *International Journal of Computer-Supported Collaborative Learning*, *8*(1), 89–112. https://doi.org/10.1007/s11412-013-9166-3

Hsu, H. Z., Witt, N. A., Hooper, J. B., & Mcdermott, A. P. (2009). The AIS-Assisted collision avoidance. *Journal of Navigation*, *62*(4), 657–670. https://doi.org/10.1017/S0373463309990099

Husjord, D. (2016). Development of a Decision Support System in Ship-To-Ship Lightering. *Journal of Navigation*, *69*(05), 1154–1182. https://doi.org/10.1017/s0373463316000126

IMO. (2015). Guideline On Software Quality Assurance And Human-Centred Design For E-Navigation. *MSC. 1/Circ.1512, 13 July 2015*.

Inoue, K., Okazaki, T., Murai, K., & Hayashi, Y. (2013). Fundamental Study of Evaluation at Berthing Training for Pilot Trainees Using a Ship Maneuvering Simulator. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *7*(2), 135–141. https://doi.org/10.12716/1001.07.01.18

Jayarathne, B. N., Ranmuthugala, D., Chai, S., & Fei, J. (2015). Accuracy of Potential Flow Methods to Solve Real-time Ship-Tug Interaction Effects within Ship Handling Simulators. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *8*(4), 497–504. https://doi.org/10.12716/1001.08.04.03

Jensen, S., Lützen, M., Mikkelsen, L. L., Rasmussen, H. B., Pedersen, P. V., & Schamby, P. (2018). Energy-efficient operational training in a ship bridge simulator. *Journal of Cleaner Production*, *171*, 175–183. https://doi.org/10.1016/j.jclepro.2017.10.026

Kitamura, K., Murai, K., Wakida, S., Miyado, T., Fukushi, K., & Hayashi, Y. (2013). Basic study of a ship navigator's mental workload using salivary NO. *IEEJ Transactions on Electrical and Electronic Engineering*, *8*(3), 301–302. https://doi.org/10.1002/tee.21856

Kunieda, Y., Yabuki, H., & Okazaki, T. (2015). Emergency Unberthing without Tug Assistance. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *9*(3), 367–374. https://doi.org/10.12716/1001.09.03.09

Last, P., Kroker, M., & Linsen, L. (2017). Generating real-time objects for a bridge ship-handling simulator based on automatic identification system data. *Simulation Modelling Practice and Theory*, *72*, 69–87. https://doi.org/10.1016/j.simpat.2016.12.011

Merriam-Webster. (2016). Merriam Webster. *Online Dictionary*.

Mitomo, N., Hikida, K., Murai, K., Hayashi, Y., & Okazaki, T. (2008). A few comments on visual system of ship handling simulator based on arriving port. *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, 1890–1894. https://doi.org/10.1109/ICSMC.2008.4811565

Miyake, R., Fukuto, J., Niwa, Y., & Minami, M. (2013). *A user test of Automatic Navigational Intention Exchange Support System using an intelligent ship-handling simulator*. *IFAC Proceedings Volumes (IFAC-PapersOnline)* (Vol. 9). IFAC. https://doi.org/10.3182/20130918-4-JP-3022.00045

Morter, P. (2015). Safety First: How simulating marine collisions can lead to a safer operating future. *Marine Log ProQuest*, *6*(120), 39.

Murai, K., & Hayashi, Y. (2010). Toward evaluation of a student's simulator training using heart Rate variability. *IEEJ Transactions on Electrical and Electronic Engineering*, *5*(3), 375–377. https://doi.org/10.1002/tee.20545

Murai, K., Shikura, A. Y. I., Ayashi, Y. U. J. I. H., Atsumoto, T. O. M., Ei, K., Uramoto, K., … Aenaka, K. A. M. (2010). Toward Evaluation of Ship Bridge Teamwork for Marine Simulator Training Based on Heart Rate Variability. *Science And Technology*, 2–7.

Nilsson, R., Gärling, T., & Lützhöft, M. (2009). An experimental simulation study of advanced decision support system for ship navigation. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(3), 188–197. https://doi.org/10.1016/j.trf.2008.12.005

Olindersson, F., Bruhn, W., Scheidweiler, T., & Andersson, A. (2017). Developing a Maritime Safety Index using Fuzzy Logics. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *11*(3), 469–475. https://doi.org/10.12716/1001.11.03.12

Orlandi, L., & Brooks, B. (2018). Measuring mental workload and physiological reactions in marine pilots: Building bridges towards redlines of performance. *Applied Ergonomics*, *69*(December 2017), 74–92. https://doi.org/10.1016/j.apergo.2018.01.005

Porathe, T. (2016). Human-centred design in the Maritime domain. *12th Biennial Norddesign 2016 Conference "Highlighting the Nordic Approach", NordDesign 2016*, *1*. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-84995921513&partnerID=40&md5=ba5730223577a41e42a72489503916d5

Saeed, F., Bury, A., Bonsall, S., & Riahi, R. (2018). A proposed Evidential Reasoning (ER) Methodology for Quantitative Assessment of Non-Technical Skills (NTS) Amongst Merchant Navy Deck Officers in a Ship's Bridge Simulator Environment. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*. https://doi.org/10.12716/1001.12.03.20

Sellberg, C. (2018). From briefing, through scenario, to debriefing: the maritime instructor's work during simulator-based training. *Cognition, Technology and Work, 20*(1), 49–62. https://doi.org/10.1007/s10111-017-0446-y

Sellberg, C., & Lundin, M. (2017). Demonstrating professional intersubjectivity: The instructor's work in simulator-based learning environments. *Learning, Culture and Social Interaction*, *13*, 60–74. https://doi.org/10.1016/j.lcsi.2017.02.003

Sellberg, C., & Lundin, M. (2018). Tasks and instructions on the simulated bridge: Discourses of temporality in maritime training. *Discourse Studies*, *20*(2), 289–305.

https://doi.org/10.1177/1461445617734956

Șerban, P. S. (2015). Case Study of Ship Squat in Sulina Channel Using NTPRO 5000 Navigational Simulator. *Applied Mechanics and Materials*, *809–810*, 1193–1198. https://doi.org/10.4028/www.scientific.net/amm.809-810.1193

Trodden, D. G., & Haroutunian, M. (2018). Effects of ship manoeuvring motion on NOXformation. *Ocean Engineering*, *150*(X), 234–242. https://doi.org/10.1016/j.oceaneng.2017.12.046

Varela, J. M., & Guedes Soares, C. (2015). Interactive 3D desktop ship simulator for testing and training offloading manoeuvres. *Applied Ocean Research*, *51*, 367–380. https://doi.org/10.1016/j.apor.2015.01.013

Varela, J. M., & Soares, C. G. (2017). Geometry and visual realism of ship models for digital ship bridge simulators. *Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment*, *231*(1), 329–341. https://doi.org/10.1177/1475090216642470

Wang, X. H., Yang, S. H., & Chen, G. Q. (2011). Design and Implement on Intelligent Target Ship for Ship Handling Simulator. *Applied Mechanics and Materials*, *97–98*, 854–858. https://doi.org/10.4028/www.scientific.net/amm.97-98.854

Weber, R., Costa, N. A., Jakobsen, J. J., MacKinnon, S. N., & Lundh, M. (2018). Assessing a maritime service website prototype in a ship bridge simulator: navigators' experiences and perceptions of novel e-Navigation solutions. *WMU Journal of Maritime Affairs*, *17*(4), 521–542. https://doi.org/10.1007/s13437-018-0155-2

Winsberg, E. (2003). Simulated Experiments: Methodology for a Virtual World. *Philosophy of Science*. https://doi.org/10.1086/367872

Xu, Q., Yang, Y., Zhang, C., & Zhang, L. (2018). Deep Convolutional Neural Network-Based Autonomous Marine Vehicle Maneuver. *International Journal of Fuzzy Systems*, *20*(2), 687–699. https://doi.org/10.1007/s40815-017-0393-z

Yang, S., & Chen, G. (2011). Study on dynamic simulation system for vessel's collision process and its application. *Procedia Engineering*, *15*, 3875–3880. https://doi.org/10.1016/j.proeng.2011.08.725

Yang, S. H., Chen, G. Q., Wang, X. H., & Yang, Y. Bin. (2011). Research on Network Communication Model of Intelligent Ship Handling Simulator. *Applied Mechanics and Materials*, *97–98*, 787–793. https://doi.org/10.4028/www.scientific.net/amm.97-98.787

Yang, Y. F., & Feng, M. K. (2014). A Comprehensive Experimental Practice for Ship Bridge Resource Management Training Based on Ship Handling Simulator. *Advanced Materials Research*, *989–994*, 5423–5426. https://doi.org/10.4028/www.scientific.net/amr.989-994.5423

Zhang, W., Goerlandt, F., Kujala, P., & Qi, Y. (2018). A coupled kinematics model for icebreaker escort operations in ice-covered waters. *Ocean Engineering*, *167*(August 2017), 317–333. https://doi.org/10.1016/j.oceaneng.2018.08.035

APPENDIX

Table 2: Presentation of the *Simulator Facility* category

Classification	Sub-classification	Publications' Names (a sample) and References
Simulator Facility	Evaluation of technology	"A Few Comments on Visual System of Ship Handling Simulator Based on Arriving Port" (Mitomo, Hikida, Murai, Hayashi, & Okazaki, 2008) "An experimental simulation study of advanced decision support system for ship navigation" (Nilsson, Gärling, & Lützhöft, 2009) "Accuracy of Potential Flow Methods to Solve Real-time Ship-Tug Interaction Effects within Ship Handling Simulators" (Jayarathne, Ranmuthugala, Chai, & Fei, 2015) (Arenius, Athanassiou, & Sträter, 2010; Bjørneseth, Dunlop, & Hornecker, 2012; Hontvedt, 2015; Jose Miguel Varela & Soares, 2017; Weber, Costa, Jakobsen, MacKinnon, & Lundh, 2018)
	Software for autonomous capability	"Deep Convolutional Neural Network-Based Autonomous Marine Vehicle Maneuver" (Xu, Yang, Zhang, & Zhang, 2018) "A user test of Automatic Navigational Intention Exchange Support System using an intelligent ship-handling simulator" (Miyake, Fukuto, Niwa, & Minami, 2013) "Developing a Maritime Safety Index using Fuzzy Logics" (Olindersson, Bruhn, Scheidweiler, & Andersson, 2017) (Ari, Aksakalli, Aydoğdu, & Kum, 2013; Benedict et al., 2014; Last et al., 2017; Wang, Yang, & Chen, 2011; S. H. Yang, Chen, Wang, & Yang, 2011)
	Software for fuel and emissions	"Effects of ship manoeuvring motion on NOX formation" (Trodden & Haroutunian, 2018) "Comparison of the Efficiency of Williamson and Anderson Turn Manoeuvre" (Formela, Gil, & Sniegocki, 2015)
	Software for human evaluation	"Quantitative projections of a quality measure: Performance of a complex task" (Christensen, Kleppe, Vold, & Frette, 2014) "A proposed Evidential Reasoning (ER) Methodology for Quantitative Assessment of Non-Technical Skills (NTS) Amongst Merchant Navy Deck Officers in a Ship's Bridge Simulator Environment" (Saeed, Bury, Bonsall, & Riahi, 2018) (Cohen, Brinkman, & Neerincx, 2015; Orlandi & Brooks, 2018)
	Software for specific operations	"A coupled kinematics model for icebreaker escort operations in ice-covered waters" (Zhang, Goerlandt, Kujala, & Qi, 2018) "Interactive 3D desktop ship simulator for testing and training offloading manoeuvres" (J. M. Varela & Guedes Soares, 2015) "Development of a Decision Support System in Ship-To-Ship Lightering" (Husjord, 2016) (De Souza, Tannuri, Oshiro, & Morishita, 2009; Șerban, 2015)

Table 3: Presentation of the *Experimental Practice* category

Classification	Sub-classification	Publications' Names (a sample) and References
Experimental Practice	Safety training	"A Comprehensive Experimental Practice for Ship Bridge Resource Management Training Based on Ship Handling Simulator" (Y. F. Yang & Feng, 2014) "Study on Dynamic Simulation System for Vessel's Collision Process and Its Application" (S. Yang & Chen, 2011) "Safety First: How simulating marine collisions can lead to a safer operating future" (Morter, 2015)
	Pedagogical approach	"The human factor and simulator training for offshore anchor handling operators" (Håvold, Nistad, Skiri, & Odegård, 2015) "On the Bridge to Learn: Analysing the Social Organization of Nautical Instruction in a Ship Simulator" (Hontvedt & Arnseth, 2013) "From briefing, through scenario, to debriefing: the maritime instructor's work during simulator-based training" (Sellberg, 2018)

		(Sellberg & Lundin, 2017, 2018)

Table 4: Presentation of the *Training and Evaluation* category

Classification	Sub-classification	Publications' Names (a sample) and References
Training and Evaluation	Evaluation of training technology	"An experimental simulation study of advanced decision support system for ship navigation" (Nilsson et al., 2009) "The human factor and simulator training for offshore anchor handling operators" (Håvold et al., 2015) "The AIS-Assisted Collision Avoidance" (Hsu, Witt, Hooper, & Mcdermott, 2009)
	Performance evaluation	"Systemic assessment of the effect of mental stress and strain on performance in a maritime ship-handling simulator" (Arenius et al., 2010) "Quantitative projections of a quality measure: Performance of a complex task" (Christensen et al., 2014) "Measuring mental workload and physiological reactions in marine pilots: Building bridges towards redlines of performance" (Orlandi & Brooks, 2018) (Kitamura et al., 2013; Murai & Hayashi, 2010; Murai et al., 2010)
	Technology on training	"Emergency Unberthing without Tug Assistance" (Kunieda, Yabuki, & Okazaki, 2015) "Energy-efficient operational training in a ship bridge simulator" (Jensen et al., 2018) "Fundamental Study of Evaluation at Berthing Training for Pilot Trainees Using a Ship Maneuvering Simulator" (Inoue, Okazaki, Murai, & Hayashi, 2013)

Table 5: Interview codes

Q1: Usage	**Q2: Opportunities**	**Q3: Challenges**
Education and training • Performing demanding tasks / operations • Individual and group training • Training novice and professionals • Leadership and joint situation awareness • Tools for enhancing safety and efficiency Research in education • Finding learning curves of student • Researching the learning in simulators • Instructor role in simulators Research in technology • Collecting physiological data • Testing new interaction designs • Data driven models for digital prototyping • Human in the loop research • Hardware in the loop research • Testing technology and algorithms • Mariner's response rates • Future projections • Offshore wind industry	Research and innovation facilitator • Innovation facilitator • Multidisciplinarity • Flexible scenarios • Connect simulator centers • Shallow water / bank effects • Docking • Complete control of situation • Proof of concept for new designs • Huge savings • Research teams / genders / cultures / groups • Training of algorithms / people / procedures • Observing the experts Developing industry workflows • Development of design methods • Convincing the industry New frontiers • Harsh environments • Autonomous vessels • More tests / scenarios / participants. Cases impossible in real life	Research infrastructure challenges • Availability of simulators • Availability of participants • Availability of technical support • Availability of maritime research partner • Data management • Availability of hardware Simulator being just a simulator • Limited setup flexibility • Duration of simulation • Location of simulation • Expensive to maintain • Bugs and shutdowns • Upgrade issues Technology readiness • Technology of sensors • Validity and reliability • Physics in co-simulation • Physics and visuals requirements • Mimic circumstances as good as possible