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Towards an Ergonomic Interface in Ship Bridges: Identification of the Design Criteria

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ABSTRACT

Despite contemporary advancements made to safety and assistive technologies within the maritime industry, approximately 80% of the accidents are attributed to human errors. One of common causations of human errors are the result of distractions produced by increasing cognitive load and inadequate working environment, which impact seafarers' decision-making abilities. Great efforts have been made to expand the technology-centred design over the last decade, however, ergonomic considerations of safety and comfort in seafarers' workplace conditions and procedures were not improved. This paper aims to study the design criteria of an ergonomic interface for a human-centred design solution to address these ergonomic issues in vessel operations, in particular the physical ergonomic and anthropometric specifications. In addition, the project seeks the assistance of digital technology to upgrade the interface design of current workplace, and further, to facilitate the design of 'a product of future ship bridge' generated for bettering seafarers' wellbeing in their workplace.

Keywords: Human-centred design (HCD), Human factors, Digital technology, Technology-centred design

INTRODUCTION

Technological innovations have improved the safety of maritime-related industries, however in the recent decades, human errors still contribute to 80% of sea accidents (Wróbel, 2021). Norman (2019) believes one of the causes is because much of our technology is designed through a technology-centred approach. He disputes the practice of design with technology at the forefront and stresses the importance of user experience (UX).

Ship bridge design is criticised over technology-centred while lacking the consideration of vessel operations as part of the design process. People expect the advanced technology will increase the number of instruments on ship bridge, so that it enhances the performance of the Officers on Watch (OOW) through reducing workload and providing a 'better situational awareness' (Hareide, 2017), ultimately, making ship operations safer. Advanced technology has reduced accidents resulting from technical failures; however, human factors associated with the use of technology continue to cause more than 1/3 of the accidents (Bielić, et al., 2017). Instead of blindly introducing new technology into ship bridge design, it is more critical to examine the situation awareness efficiency supported by technologies. Technology evolution results in the complex interfaces of products, systems, and workplaces; in particular, the multimodality interfaces which display various and numerous information, and ultimately challenge users to recognise and interact with (Guo, et al., 2021). The consequent distractions become potential negative factors affecting work efficiency and safety.

Norman (2018) introduced the human-centred design (HCD) method that aids to identify and fix the real and underlying problems in current ship bridge design, in terms of the equipment, layout, and working procedures aimed to eliminate most errors caused by humans. It is imperative to optimise the bridge design using human-centred participatory design approach, to upgrade human machine interaction (HMI) with the minimum cognitive load.

HCD takes account of people at the centre of design, to improve their experience when using or interacting with products, systems, and environments (Giacomin, 2015). Human Factors/Ergonomics (HF/E) refers to the application of psychological and physiological principles to the design of products, processes, and systems (Wickens, et al., 2003). This scientific discipline focuses on understanding people's needs, abilities, and limitations with the purpose of designing adequate interaction systems (IEA, 2014).

Currently, most ship designers focus on the physical ergonomics, and in the research of seated wheelhouse cockpit designs that integrate equipment around anthropometrics, such as the line of sight, to assure information to be more accessible for the OOW. Grech et al. (2008) have upgraded this to list the lack of standardisation as one of the primary HMI issues on-board ships, and the lack of usability, information overload, and ergonomic integration in design. These concepts, however, did not consider the ship bridge as an 'all in one product' with a multimodality interface. This paper aims to investigate the specifications for the design of 'a product of future bridge', where the concept integrates all the equipment in the ship bridge as the parts of a product, finally, to function as one system or product.

UPGRADING INTERFACE DESIGN THROUGH HUMAN-CENTRED DESIGN

HCD is commonly applied in the design industry and is characterised as a multi-stage problem-solving process. Researchers argue that current methods of reducing human error at sea require a different approach to existing models of accident mitigation. Apostol-Mates and Barbu (2019) describe the human element in a study regarding accidents involving fatigue as "the central pillar of the system", signifying the importance of the human element in operating the vessel is beyond the mechanical and technological elements. Norman (2019) agrees that the reliance on technologies within the industry creates a hostile environment for humans. He disputes the practice of designing with technology and suggests that the UX should come first. Likewise, Costa (2016) suggested that applying the HF into the design of vessels will potentially alleviate the number of human errors.

The Ergonomics.org.uk (2012) defines HF is about 'fit': the fit is between people, the objects, and the environments they use or work. The objective of HF is to design systems, jobs, and organisations that match human capabilities to reduce human errors, increase productivity, and enhance safety or comfort with a specific focus on the interaction between the human and the thing of interest (Wickens, et al., 2003). HF incorporates three domains: the physical, cognitive, and organisational ergonomics (IEA, 2014). These three criteria dictate the quality of design and assist how the design interacts with human elements. Basically, the physical ergonomics benefits modern specialised ship design to satisfy OOW's requirements. Cognitive ergonomics emphasises the interface design process to reduce users' cognitive workload. Organizational ergonomics takes account of the workflow structure of bridge operations, which can increase or decrease pressures during the process of decision making in the ship bridge. Therefore, HF participation in HCD expects to promote overall system design results and increase life cycle cost savings (Hendrick, 2008) by better integrating users, machines, and work environment to increase production efficiency, minimize errors, and improve user trust and system reputation (Maguire, 2001).

IMO GUIDELINES ON SHIP BRIDGE DESIGN

Established in 1948, the International Maritime Organization (IMO) has issued a number of regulations to provide machinery for cooperation among governments worldwide; it encourages and facilitates the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation, and the prevention and control of marine pollution from ships (O'Neil, 2011). IMO keeps adopting recommendations and revising existed regulations. Between 1997 and 2003, IMO introduced and revised human element vision, principles, and goals respectively, which begin to proactively identify the HF-related safety issues (Schröder-Hinrichs, et al., 2013). The Guidelines on Ergonomic Criteria for Bridge Equipment and Layout developed and announced in 2000, aimed to pursue a successful ergonomic design of the bridge and bridge equipment, containing ergonomic requirements and pragmatic layouts to support OOWs in their tasks based on the theory of HCD. The guideline detailed ergonomic requirements for seven aspects (i.e. Bridge layout, Work environment, Workstation layouts, Alarms, Input devices, Information display, and Interactive controls), and incorporates interface and interaction criteria physically and virtually, for designers, manufactures, and ship owners to follow and review.

In 2003, the Maritime Safety Committee (MSC) highlighted the issues that need to be considered when introducing new technology on board ships, to guarantee the effectiveness of seafarers operating the new technology safely (IMO, 2003). MSC discussed issues regarding the adoption of new technologies into vessels, concerning factors such as familiarity with equipment, the variety of user interfaces (UIs) between vessels, interface symbology, behavioural patterns of inexperienced seafarers under stress, a quantity of information, and lack of understanding regarding the limitations of automation at the time. In 2006, MSC developed new performance standards for

Electronic Chart Display and Information System (ECDIS). The guidelines for the presentation of navigation-related symbols, terms, and abbreviations were amended in 2019. ECDIS became more mature in both its technology and implementation within ships, as new standards became the norm, which made ECDIS more user friendly, realising its potential, as discussed within the annex of MSC Circular.1503 in 2017. Thus, cementing the implementation of digitalised ship environments for the foreseeable future.

ADOPTING DIGITAL TECHNOLOGY

The emerging technologies provide new ways to display information and interact with users, further, to help mitigate risk and enhance seafarers' performance in vessel operation. This paper studied a variety of advanced interactive and display technologies that targeted to minimise the distractions for OOWs within ship bridges, to reduce their cognitive workload, and to relieve pressure during decision-making processes.

Augmented Reality (AR) overlays computer-generated digital elements onto the real world via a tight integration of camera hardware and software. This technology has been widely adopted in consumer product design such as smartphones, and other sectors. Recently, Furuno (a historical Japanese supplier in the maritime field) applied AR to the Envision Navigation system, aiming to enhance seafarers' navigational performance. Likewise, the Ocean Industries Concept Lab (OICL) in Norway, released a video displaying a concept of AR ship navigation. Differing from Furuno, OICL used the head mounted display (HMD) to overlay information on the sight field of seafarers and provided seafarers with more flexible and moveable visions.

Virtual Reality (VR) technology especially the VR HMD can offer affordable and highly immersive experience to users. The technology has widely benefited education and the training domain. The "sense of being there" enables experiential learning in simulated virtual environments effectively (Stevens and Kincaid, 2015), where seafarers can acquire accurate spatial information with a meaningful, contextual, and scenario-based learning experience (Renganayagalu et al., 2021).

Mixed Reality (MR) provides better experience to AR as it incorporates VR, which allows for greater interaction. Microsoft (2021) has also developed its second-generation headset 'the HoloLens2'. The MR blurs the boundaries between real and virtual and supports both interactions with real and virtual context.

Cognixion One is defined as the world's first brain computer interface with augmented reality wearable speech generating device (Cognixion, 2020). The technology combines AR and upgrades Electroencephalogram (EEG), in which the incoming data is interpreted by a machine learning model to accelerate teasing out signals and making predictions, to help those who struggle with communication, so as to provide users visual, voice, and brain UI to smoothly interact with (Coldewey, 2020). Like a heads-up display, the visual UI is reflected to a transparent surface as an overlay of information, while audio and speakers ensure the product's ability to communicate with users by voice. However, the additional benefit is to read electrical activity within the brain to determine what is displayed. Therefore, this technology can also be used to measure stress, cognitive load, and fatigue through the headset.

Surface Dial is a product of Microsoft released in 2016. Microsoft defines it as a product able to "Store, customise, access, navigate and reimagine physical tools in the digital world – from concept to creation" (Microsoft, 2020). It is expected that Dial will create the most natural and immersive way for users to interact with, and further to build an intuitive connection between virtual interfaces and physical moves.

Given the above, these advanced display and interactive digital technologies demonstrate great potential to exhibit information, promote HMI, and further upgrade current interface of the bridge ergonomically.

BEHAVIOURAL MAPPING OF THE OOWS

Recently, an approximately 60 minutes' simulation exercise was set up by the authors of this paper in a 360° ship bridge simulator. The task was designed as a voyage planning of 'arrive at a port', which involved managing temporary/emergent events during the vessel operation, such as performing urgently when the harbour is suspended due to strong winds and handling a fire alarm emergency. Four experienced deck officers participated in this exercise, including a Master, two OOWs (a and b), and a Helmsman. The master leads the team and holds full awareness and knowledge of the task and working situation. The two OOWs executively operate the vessel with the assistance of numerous digital and manual equipment at the workplace. Helmsman, however, followed the OOWs commands to concentrate on the manual steering during the entire operation.

Figure 1 visualises the floor plan of the workplace that consists of a Conning Station, two Radars, two ECDISes, a Helmsman Station, a Pelorus, and two Common Stations equipped with Radio, VHF, telephone, and fire alarm systems. Behavioural mapping was performed based on the entire process of the task, to record individual's working position and trajectories of their eye focal points and body movements respectively.

The Master's map (see Figure 2) demonstrates that the major working position of the Master is next to the radar on the right, where he/she is frequently checking the radar and looking out through front windows. He/she often communicates with the OOWs; however, has very seldomly interacted with the Conning Display, the ECDIS, and the Common Station. Given these observations, it can be learnt that the radar is the primary equipment that the master interacts with, and looking out is his/her major activity.

The two OOWs shared the same duty in this task; however, they have played different roles individually. The OOW(a)'s major working position is next to the Conning Station, where he/she often interacts with the Radar and the ECDIS on the left side. Whilst interacting with the Conning Display, OOW(a) has also frequently looked out and communicated with the Helmsman. Whereas OOW(b)'s major working position is close to the Master and is next to the Common Station on the right. He/she often interacts with the ECDIS, Radar, and performs looking out through all windows. OOW(b) often checks paper charts, keeps a stand-by for external and internal communication via

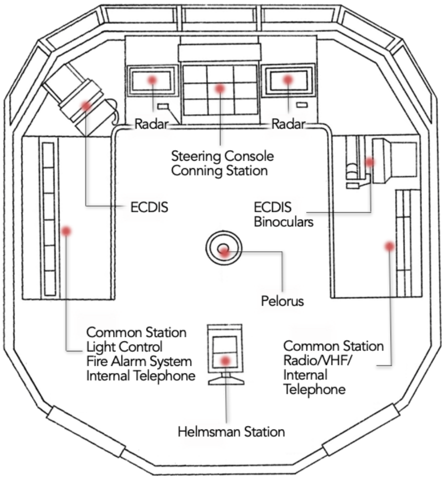

Figure 1: Floor plan.

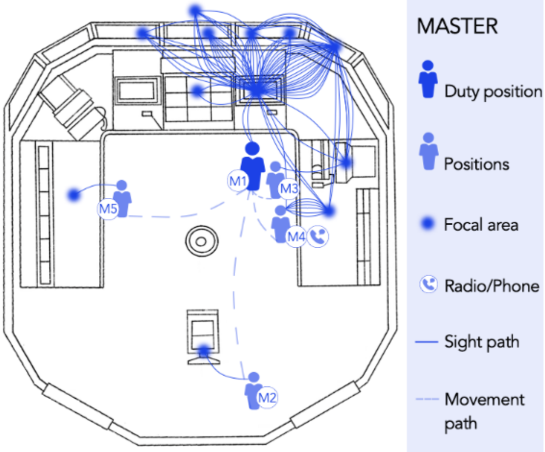

Figure 2: Behavioural mapping of master.

VHF/radio/telephone supplied on the Common Station, and works flexibly and exhibits the most complicated routes inevitably (see Figure 3).

The Helmsman displayed a simple behavioural map with a fixed working position at the Steering Station. He/she follows the OOWs commands to steer manually and keeps looking out from all windows almost simultaneously.

The preliminary results indicate that the Radar, ECDIS, Conning Display, and Steering Station appear to be the most significant equipment required during vessel operation. Meanwhile, paper charts seem quite important and necessary, and cannot be completely replaced by ECDIS, in case the digital equipment fails to work due to unexpected events and leading to accidents. In addition, more than one ECDIS and Radar may be needed in the bridge, if more OOWs work in a tight space at the same time. It indicates that a multi-modality interface may be an ideal solution to present multiple information within a limited space.

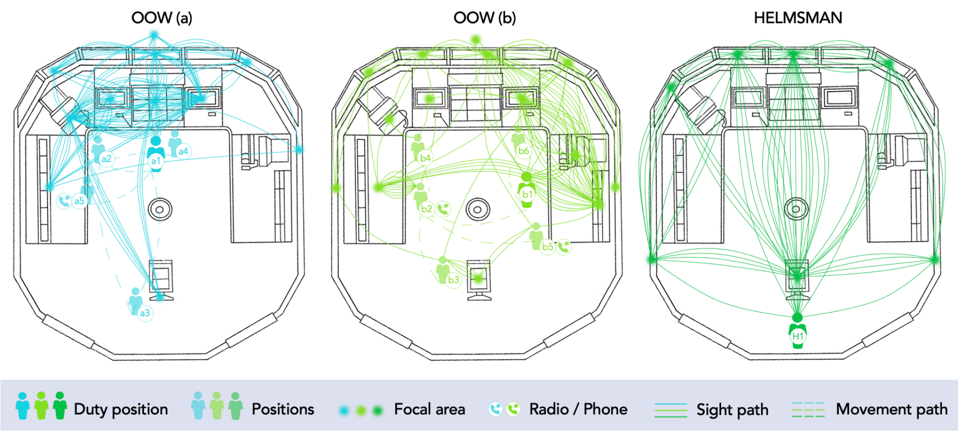

Figure 3: Behavioural mapping of OOW (a), OOW (b), and Helmsman.

DISCUSSION

The findings of primary and secondary research provide an essential foundation of HCD specifications for the next generation of bridge designs, including ergonomic requirements and practical layouts that target to pursue a successful ergonomic design of the bridge and bridge equipment to support OOWs in their tasks.

The three dimensions of HF supply comprehensive assistance in HCD. Physical Ergonomics offers anthropometric standards to exam and improve OOWs' working postures, manual steering, repetitive movements, and workplace layout, thereby reducing distraction. Cognitive ergonomics, in particular the study of symbolic qualities of man-made shape in the cognitive and social context of their use, can facilitate people's cognitive ability, so as to assist HMIs, when people do not respond to the physical qualities of things but act on what they mean to them (Krippendorff, 1984). Finally, organisational ergonomics serves to optimise the workflow structures, policies, and processes, to enhance communication and assist the teamwork, thereby, to increases or decrease the pressure of HMI's effecting on decision making.

IMO keeps updating guidelines on ergonomic criteria for bridge equipment and layout, and revising existing regulations for workstations such as navigating, monitoring, Helmsman operations, docking, planning, safety, and communication. It also details ergonomic requirements including Bridge layout, Work environment, Workstation layouts, Alarms, Input devices, Information display, and Interactive controls. MSC often renews performance standards for ECDIS guidance of good practice, the presentation of navigation-related symbols, terms, and abbreviations.

The emerging display and interactive digital technologies provide the feasible and practical solutions to upgrade current UIs of ship bridge. The AR HMD overlays information on the sight field of seafarers to provide seafarers with more flexible and moveable visions. The VR HMD, however, offers highly immersive experience to users. Cognixion One combines AR and upgraded Electroencephalogram (EEG) to supply users with visual, voice, and brain UI interactions. Further, this technology can measure stress, cognitive load, and fatigue through the headset. Ultimately, Surface Dial plants "physical tools in the digital world" (Microsoft, 2021), creating an immersive way in building an intuitive connection between virtual interfaces and physical moves.

The data collected from the behavioural mapping indicates that Radar, ECDIS, Conning Display, and Steering Control are four vital pieces of equipment required in vessel operation, together with paper charts, which appear to be a necessary substitution of ECDIS. These findings have confirmed the hypothesis of creating a simple and multimodality interface with intuitive interaction as an ideal solution to reduce the amount of physical equipment, to minimise distractions, and to improve the OOWs' working conditions.

CONCLUSION

Given the above discussion, the preliminary design criteria can be concluded to incorporate (a) following the IMO guidelines and the MSC regulations, (b) applying the three dimensions of HF in HCD, (c) satisfying the findings indicated in the behavioural mapping, and (d) adopting the state-of-the-art digital technologies. These four criterions will form an experimental concept, to address ergonomic issues through upgrading the interface design of current workplaces. Further, the concept will be evaluated via a usability test undertaking in a focus group discussion later, to finalise a validated design criterion, thereby to drive the formal prototype of 'A Product of Future Ship Bridge'.

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