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Bridge Ergonomic Design: A Review

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ABSTRACT: Human error remains the most common cause of marine incidents and it is worth emphasizing that navigator's performance is directly affected by ergonomic factors on the bridge. Studies regarding influence of bridge design and work environment on the operator are rare, thus the main purpose of this paper is to fill in this gap. Documents issued by recognized organizations, research publications and additional sources were reviewed to check if navigators obtain enough support in this area and what should be improved. It was found that present ergonomic guidelines for the bridge design require revision and there is a need for making the regulations more meaningful and direct. The main documents that require reworking include Guidelines on Ergonomics Criteria for Bridge Equipment and Layout, International Convention of Standards of Training, Certification and Watchkeeping (STCW) as well as selected parts of SOLAS V/15 regulation.

1 INTRODUCTION

As of 2022, vessels are responsible for about 80% of international trade's volume. According to [48] average time spent in port per vessel in 2020 was only 1.00 day. Minimizing the time spent in port and making mooring and cargo operations shorter reduces costs of ship-owners or charterers. On the other hand, it may result in increased fatigue of navigators during their bridge watch when underway [1]. The latter is an issue addressed by the current paper.

In general, the problem of human fatigue is directly addressed by ergonomics [13]. Ergonomics is a study of working environments, their components, work practices and procedures for the benefit of the worker's productivity, health comfort and safety [32]. Unacceptably high levels of human error, injuries or poor quality are considered as system problems [6]. Consequently, ergonomics' main goal is to improve human safety, health, comfort and performance by means of system design [8]. Thus, it is easy to observe that ergonomics is crucial in navigation context, where, due to its complexity, the integrated bridge can be classified as a system of systems [36] and where human errors can be particularly dangerous.

Analysis of marine accidents is showing that human error percentage is decreasing in recent years but still constitutes 60% to 80% of all causes [45]. Admittedly, those errors are not only related to ergonomics but also lack of knowledge, neglect of duty or miscommunication. However, there are plenty of factors that can increase fatigue-related human errors on board ships. They include intensive traffic density, port and cargo operations as well as darkness or bad weather condition. Global crew change crisis in 2020 and 2021 caused by COVID-19 pandemics has a major impact on seafarers' health and wellbeing, including such problems as fatigue, anxiety and mental health issues [2] and decreasing number of crew on board leads to increased workload and fatigue [3]. Minimum

Safe Manning Certificate is setting minimum standards in this case. However, keeping only the skeleton crew might result in reduction of safety level. Taking into consideration that some tasks (like mooring or cargo operations) are unavoidable and that ship crew can be performing their duties for a few months without a single day off, the fatigue might become a serious problem. It affects seafarers' ability to perform their job effectively and safety [26] and degrades cognitive skills, slows down reaction time, reduces vigilance and affects decision making [46].

Implementation of new equipment including the concept of e-Navigation is supposed to increase navigational safety and security [50]. On the other hand, the system's complexity and overload of information can have an opposite effect. Especially, when it is combined with overreliance on aids and electronic equipment, which reduce watch keeping standards [12]. Safety of marine navigation is further affected by non-technical skills of the crew, including situation awareness, decision making and management skills [43]. Bridge designers and equipment manufacturers alike should therefore look for a balance between reducing work overload and keeping the tasks sufficiently involving for a human operator.

A lot of works related to ergonomics or human factor are applicable to the navigational bridge. However, the influence of the wheelhouse design, layout or indoor conditions on navigator's performance is rarely researched. Thus, main purposes of this paper are to fill in the gap in literature and investigate if there is still room for improvement here. To achieve those goals it is necessary to review legal regulations in the field of ergonomic design of the bridge and check if navigators get enough support here from the regulatory bodies. Following this, the regulations and their development can be confronted with the technological progress.

1.1 *The process of navigation*

Navigation can be considered a process of safe and efficient operation of the ship at sea [34]. A simplified model shown in Figure 1, based on Jurdziński [33], indicates that one of the most important factors is observation of the surroundings of the vessel. According to Rule 5 of Convention on the International Regulations for Preventing Collisions at Sea (COLREG): "every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision" [19]. However, ship as a structure does not look-out, observe surroundings and assess the situation – these duties are carried out by a qualified officer in charge. Neither sight nor hearing can be replaced by technology and ergonomic design of navigational bridge, which supports those senses, is thus essential for watch keeping.

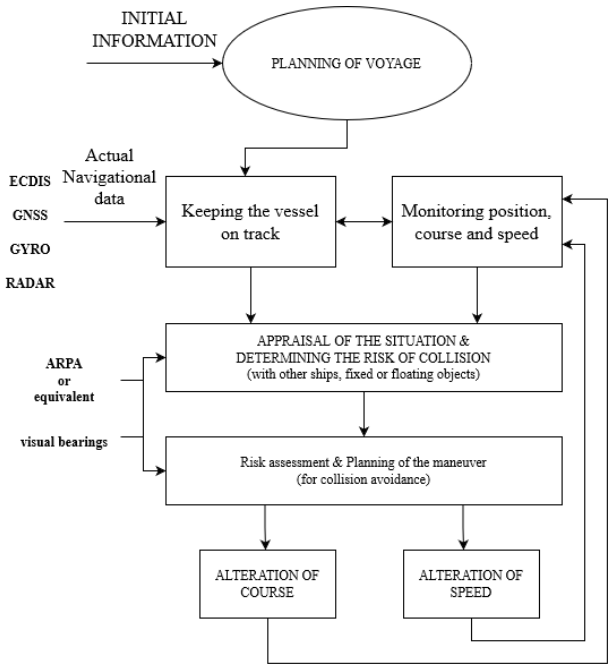

Figure 1. Simplified model of the process of navigation, based on Jurdziński [33].

1.2 *Bridge as a command centre*

Bridge is the main command centre of the vessel [39]. Navigator's duties, apart from those in Figure 1, include voyage documentation, routine testing of equipment and supervision of the works carried out on deck. That is why there are some workstations on the bridge with different equipment or use purpose. E.g., the suggested layout of wheelhouse, which is shown in Figure 2 and can be found in MSC/Circ.982 (Guidelines on ergonomic criteria for bridge equipment and layout) or in ISO 8468:2007 (Ship's bridge layout and associated equipment – Requirements and guidelines).

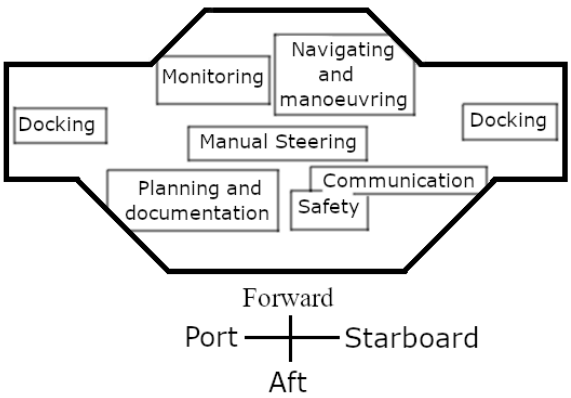

Figure 2. Suggested layout of workstations on the bridge, based on International Maritime Organization [27] and International Organization for Standardization [32].

The workstations on the bridge have different purposes, which are listed below:

- Workstation for navigating and manoeuvring – the main one, should provide optimum visibility, integrated presentation of information and operating equipment to control and consider ship's movement.
- Workstation for monitoring – for permanent monitoring of equipment and surrounding environment from seated/standing position.

- Workstation for manual steering – the vessel can be steered by a helmsman in accordance with orders given by the navigator in command.
- Workstation for docking – it should be located on bridge wing and allow navigator (and pilot if applicable) observe all external and internal information required for safe operation and manoeuvring.
- Workstation for planning and documentation – intended for planning ship's operations (e.g. route planning or filling the deck logbook during the voyage).
- Workstation for safety – displays and operating elements serving safety should be located here. This might include control of internal emergency with an access to internal or external communication related to safety of the ship.
- Workstation for communication – designated for operation and control of general communication and Global Maritime Distress and Safety System (GMDSS) equipment [27] [14].

The requirements for the field of vision from each workstation are described in International Convention for Safety of Life at Sea (SOLAS) Chapter V Regulation 22, while proposed equipment for workstations can be found in MSC/Circ.982.

2 SOURCES OF REGULATION

The IMO is a specialized agency of the United Nations, gathering 174 member states and 3 associate members in 2021 [21]. It plays a crucial role in forming of the international law of the sea and is the most important link in the process of globalisation of shipping standards and regulations [7]. In order to improve safety, IMO has promoted adoption of conventions, codes, recommendations etc. [47], providing the main source of information on bridge ergonomics and design criteria.

SOLAS was adopted in 1974 and entered into force on 25 May 1980. Its main purpose is to determine minimum standards for construction, equipment and operation of vessels. Flag states are responsible for ensuring that ships under their flags meet those requirements [20].

International Convention of Standards of Training, Certification and Watchkeeping (STCW) from 1978 is adopted worldwide to regulate crew operations, medical requirements, competence standards etc. Since STCW Convention entered into force on 28 April 1984, a lot of amendments have been adopted [22]. Similar situation takes place with SOLAS Convention, which allows keeping the documents up to date [20].

Another international convention, Maritime Labour Convention (MLC) was established in 2006 by ILO. This is a massive boost for seafarers, as the convention sets minimum working and living standards onboard ships under flags of ratifying countries. As of now, the MLC Convention has been signed by 98 member states which covers about 91% of world shipping [17].

In 2018, SOLAS and STCW each had 164 contracting governments and each covered over 99% of merchant fleet around the World in terms of gross tonnage [38]. The other reason of worldwide acceptance of IMO documents, except from increasing safety and unification of standards and rules, is simply the difficulties that can be experienced by ships of States, which are not Parties of international conventions.

Standards for ship safety, after being set by IMO, are applied by national maritime authorities and classification societies. They also offer assistance to maritime industry and regulatory bodies regarding safety and pollution prevention basing on the knowledge, experience and technology. Classification Societies can publish and apply their own rules and verify regulations on behalf of flag Administrations. The biggest and most reputable of those organizations can become members of IACS.

2.1 *Changes in bridge equipment*

The minimum standards for the navigational equipment and systems are described in the SOLAS, Chapter V, Regulation 19. Required equipment varies depending on the engagement on international voyages, year of built, type of ship or gross tonnage [23]. The requirements for compulsory navigational devices carried on board are revised by IMO in form of amendments to SOLAS.

Since 2000, the navigators experienced major changes due to new bridge equipment. The first of them was Automatic Identification System (AIS), which was made mandatory by SOLAS. Due to terrorist attacks in the United States in September 2001, the deadline of implementation was revised and shortened to 31st December 2004 [41]. SOLAS was also amended by IMO in 2009, regarding introduction of Bridge Navigational Watch Alarm System (BNWAS). Since then, all new ships of 150 GT and upwards, all new passenger vessels constructed after 1st July 2011 shall be equipped with this system. Existing ships were to introduce BNWAS before certain deadline dates dependent on the gross tonnage [28]. The same can be observed for ECDIS, as the changes of requirements were adopted in the same year and document as BNWAS. The introduction started from passenger ships of 500 GT and upwards and tankers of 3000 GT and upwards constructed on or after 1st July 2012 [28]. On 1st July 2018 the transitional period of implementation expired and since this time all vessels of 3000 GT or more involved in international voyages must be fitted with an official ECDIS system. Nowadays it is common to have ECDIS only and no paper charts on board. Modern ships do not have chartrooms, so back-up ECDIS fitted on the workstation for monitoring can be considered a part of the workstation for navigating and manoeuvring and may serve as additional conning station [14]. The introduction of new mandatory navigational equipment since the adoption of MSC/Circ.982 is summarised in Figure 3.

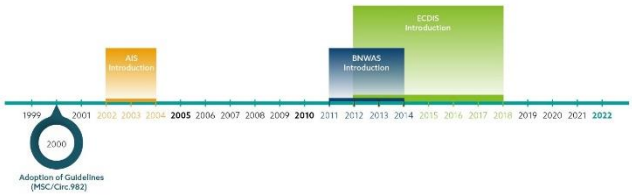

Figure 3. Introduction of new mandatory navigational equipment since 2000.

3 ERGONOMICS IN REGULATIONS

From the regulatory perspective, the design of the bridge should support the operations, according to SOLAS Chapter V, Regulation 15 [23]. Apart from those mandatory SOLAS requirements for bridge arrangement or equipment, navigation bridge is additionally supported by non-mandatory standards and guidelines [25]. This includes MSC/Circ.982: Guidelines on ergonomic criteria for bridge equipment and layout, which was issued by the Maritime Safety Committee in 2000. The intention of this document was to assist designers to perform sufficient ergonomic design of the bridge, as described in Regulation 15 of chapter V of the SOLAS Convention [27]. These supplemental standards are essential, as the rules are very general and state that the design should:

- promote the effective and safe bridge resource management,
- prevent or minimize excessive or unnecessary work,
- facilitate tasks to be performed by bridge team and pilot in making full appraisal of the situation and in safe navigation of the ship in all operational conditions etc.

Other guidelines in the topic of bridge design provided by IMO in forms of circulars are:

- SN.1/Circ.265: Guidelines on the application of SOLAS V/15 to INS, IBS and bridge design,
- SN.1/Circ.288: Guidelines for bridge equipment and systems, their arrangement and integration (BES).

There is an ISO standard 8468:2007 (Ship's bridge layout and associated equipment – Requirements and guidelines) providing information on human factor in bridge design, e.g. specify functional requirements for bridge and workstation arrangement or the working environment. The guidelines are suggested to be used as methods and solutions for meeting the functional requirements. Although most of the guidelines included in MSC/Circ.982 directly match this document, ISO standards are non-mandatory, unless stated otherwise in regulations [31].

MLC Convention from 2006 provides some more regulations. According to this document, work environment should promote health and occupational safety in living, working and training [18]. In the Convention itself, there is mentioned a problem of exposure to noises and vibrations. Those and other harmful factors like lighting, UV lights, extreme temperatures or radiation are better explained in the Guidelines for implementing the occupational safety and health provisions of the Maritime Labour Convention, 2006, issued by ILO in 2015. Those guidelines, apart from dealing with exposure to work environment, address also ergonomic hazards or fatigue as other forms of risks on-board [16].

STCW Convention provides standards regarding training and watchkeeping. In the minimum standard of competence for deck officers there is no direct requirement related to keeping proper ergonomics while performing duties on the bridge. There are references and examples of areas that should be given great care, e.g. taking over the watch. To promote safe and effective take-over of duties, STCW contain a requirement concerning the adjustment to the light conditions, particularly to night vision. However, STCW Convention does not specify neither the exact period, which is sufficient for adapting to darkness, nor the means to evaluate night vision [51]. Moreover, the officer shall ensure that all members of the watch are fully capable to take over the duties and relieve the previous watchkeepers [24], not being supported by any suggested methods of verification of compliance. Above-mentioned non-mandatory standard ISO 8468, which was revised in 2007, provides additional guidelines, including using red goggles for 5-15 minutes before a watch to support adapting to darkness (this is not mentioned neither in MSC/Circ.982 nor in other reviewed documents issued by IMO).

IACS issued a recommendation containing the application of above-mentioned SOLAS Regulation V/15 in 2007 [14]. The document was later corrected in 2009 and 2011. Some classification societies promote application of ergonomics and human factor in design by issuing their own guidelines or rules.

3.1 *Guidelines: deeper look into standards*

To show the technological progress in recent years, the appendix 3 of MSC/Circ.982 was analysed. This appendix contains standards dealing with ergonomic criteria for bridge equipment and layout as of 2000. They are grouped in table in the Appendix 1 to this paper.

The analysis can be summed as follows:

- ISO 14612 was established in 1999 to strengthen ISO 8468 [11], however it has been replaced by ISO 8468:2007 [32].
- The guidelines for workstations and suggested equipment on them was included in the MSC/Circ. 603 Annex 2 from 1993, but it was overtaken by time by the MSC/Circ.982 itself [25].
- In addition to general requirements for GMDSS equipment and electronic navigational aids set out in resolution A.694(17), the new display performance standards were described by resolution MSC.191(79) adopted in 2004.
- Alarm management performance standards described in resolution A.694 (17) were extended by resolution MSC.302(87) adopted in 2010 [29].
- The IEC 61209 titled Operational and performance requirements, methods of testing and required test results for Integrated bridge systems (IBS) was withdrawn in 2013 [15].
- Revised performance standards for Integrated Navigation Systems (INS) were introduced in 2007 by resolution MSC.252(83)
- The relevant requirement for work environment was introduced to SOLAS in 2012. According to

adopted amendments, newly built vessels should be constructed in accordance with Code of noise levels on board ships. The code sets noise level limits and is mandatory for new built ships for spaces on board including navigational spaces [30]. Guidelines for noise on the bridge provided in MSC/Circ.982 are general and do not specify maximum allowed noise volume. It is however stated that it should not interfere with necessary communication, cause fatigue or injury and degrade overall system effectiveness.

4 DISCUSSION

Ship crews are working in a difficult and stressful environment [10]. To avoid the problem of work overload, a bridge team can be temporarily enlarged [37], however this is hard to apply in practice. Therefore, There are some possible methods of fatigue reduction, including properly applied ergonomics [44]. Ergonomic design supports also minimum manning of ships [42], which is essential during crew change crisis and when personnel on board is reduced to skeleton crew.

As was stated in 1989 in by Larsen [35], bridge ergonomics is one of the areas where navigational safety can be enhanced. However, the content of SOLAS Regulation V/15 related to bridge design, remains very general and does not specify methods of compliance. As noticed by Grech and Lemon [5], it is desired to point out strict responsibility of authorities for execution of bridge ergonomic design. Unfortunately, not all flag states fulfil their duties concerning the compliance with international conventions [40], which makes implementation of non-mandatory ergonomic standards to the bridges unlikely. Specifically, questions have been raised about whether this Guideline adequately addresses the gaps within the Safety of Life at Sea (SOLAS), Regulation V/15, which deals with bridge ergonomics. One aspect under consideration is whether a link should be made between the Guideline and SOLAS regulation V/15 with the possibility of including a reference to the new Guideline in a footnote to SOLAS regulation V/15. While other SOLAS Regulations place strict requirements on contracting Governments (for example), Regulation V/15 seems to be missing any actionable responsibility associated with bridge design-related issues.

4.1 *Tackling the problem by design or by training*

Navigator's work is affected by multiple ergonomic factors. This include body posture and movement, environmental factors, information and operation or the work organization [8]. The purpose of bridge ergonomics is not only to support health and occupational safety, but also to ensure safety of the whole ship, e.g. when determining risk of collision and monitoring the effectiveness of collision avoidance action. With respect to COLREGS, the proper lookout should be maintained all of the time. Therefore navigator should be provided with a good view from seated position, proper lighting and low noise level.

Ship designers are very often limited in their work by cost cutting, structural stresses or limited space. At the same time, they are expected to address the needs of vessel crews, even though they have little to no contact with the latter and are unable to predict their work routines. Poorly fitted equipment in combination with low usability causes a long-term problem for the operators [5]. In the beginning of 2020, the average of age of global fleet was 21.29 years old in terms of number of ships [49]. Considering that the ergonomic guidelines issued as MSC/Circ.982 were adopted in 2000, it is unlikely that bridges were designed with ergonomics in mind before this date. These ships however still operate worldwide without any additional support for navigators. This results in an increased workload in comparison to bridges with ergonomic work environment, especially considering that the standards of competence and operators' licenses are the same in both cases, as are the minimum manning requirements.

Seafarers' fatigue can be reduced by introducing ergonomic standards as well as professional education [4]. If a bridge design does not support ergonomic principles (e.g. on ships built before the adoption of guidelines from year 2000), than at least a proper training should be offered to back-up officers. Otherwise, the situation might lead to poor ergonomic awareness among seafarers and result in bad habits and inefficient use of provided equipment.

Training in ergonomics might not only teach navigators healthy routines but also provide support in controlling ergonomic factors on the bridge and in taking collision-avoidance decisions in case of quick change in weather conditions. A lot of emphasis has been put on teaching the use of navigational equipment, however, it should be highlighted that the whole bridge environment, including ergonomic factors, is important for performing the duties and is controlled by the officer in charge. Even if the whole area of wheelhouse is provided with flexible light adjustment and individual dimming functions, those devices will be operated by a human navigator, who must know when and how to use them in order to improve his performance.

5 CONCLUSION

All parties involved in shipping try nowadays to follow the "safety first" watchword. Ergonomic factors have direct influence on the duties of navigator, including proper lookout. Taking into account the number of accidents involving human error, the problem remains unsolved and there is clearly need for further research and more restrictive regulations.

Ergonomic related problems are already known to the maritime industry and they are tackled by implementation of standards, rules or guidelines, which are often unclear or too general. Cooperation of all key actors is thus required for solving the problem and reducing its negative influence on navigators. Since ship designers usually lack navigation background, they need to be supported by standards and guidelines, all of which should be revised frequently.

This paper has shown that there is a regulatory gap for the work environment on the bridge. With the sole exception of noise limitation since 2012, there are only recommendations, guidelines and other non-mandatory documents on bridge ergonomics. Unfortunately, they are not strong enough to enforce compliance with them. Such gap exists also regarding the seafarers training covered by STCW, which does not support controlling the work environment, e.g. proper adjustment of lighting and illumination on the wheelhouse.

Also, ships older than 20 years are a significant percentage of worldwide fleet. Guidelines on Ergonomics Criteria for Bridge Equipment and Layout (MSC/Circ.982) were adopted in 2000 and up till now there were no revisions. In 2020 the average age of the global fleet was 21.29 years, which is a problem, as old ships' bridges were not designed to comply with the present ergonomic guidelines. Thus, additional actions by IMO might be necessary to support ergonomics, including extra training. Further study is required to assess the real scale of this problem, but there is definitely a need for improvement: among others, SOLAS V/15 regulation could be more direct, having in mind bridge operators.

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