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Investigation of the engine control room design, ergonomics, and function

Bachelor thesis in Marine engineering program

STEFAN ANDERSSON, AXEL LINSE

DEPARTMENT OF MECHANICS AND MARITIME SCIENCES
DIVISION OF MARITIME STUDIES

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STEFAN ANDERSSON, AXEL LINSE

Department of Mechanics and Maritime Sciences
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

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Abstract

The Engine Control Room (ECR) on board a vessel is the heart of the engine department, where monitoring and operation of numerous systems takes place. It is a vital area for the operation of the vessel. The ECR on board have during the last decades continuously developed towards becoming more computerized, which has had an impact on how the work in a control room is conducted. Analogous equipment is, in many cases being replaced by digital interfaces on computers, which creates a different work area and situation. Engine control rooms are still designed traditionally and have not adapted to the changes in technology and task performance. The purpose of this thesis was to investigate, from the crew's perspective, what needs to be improved with regards to engine control room design, ergonomics, and function. This was done through focus group workshops, with marine engineering students and marine engineers. A qualitative research approach with thematic analysis for data interpretation was used. The goal was to find recommendations for ECR ergonomics and design standards. The result of the study shows that the ECR is to a large extent mismatched against todays expected work in the ECR. None or very few general developments towards a better working environment in the ECR over time could be endorsed by participants of the focus groups. Ergonomic features, design, and function of the ECR are still considered to be non-prioritized, most likely due to the lack of mandatory regulations.

Keywords: engine control room, ergonomics, ships, engine room, work environment, regulations

CONTENT

1 Introduction

The Engine Control Room (ECR) on board a vessel is the heart of the engine department, where monitoring and operation of numerous systems takes place. It is a vital area for the operation of the vessel. The ECR on board vessels have during the last decades continuously developed towards becoming more computerized, which has had an impact on how the work in a control room is conducted. Analogous equipment are to a large extent being replaced by digital interfaces on computers which creates a different work area and situation (Mallam & Lundh, 2013). The operators in technologically highly sophisticated control rooms are now facing different challenges in operating the systems, compared to operators of previous generations of equipment. Although the advancements in technology can be seemingly positive in many aspects, control rooms are still designed traditionally and have not adapted to the changes in technology and task performance (Lundh et. al., 2011; Wagner et. al., 2008).

In the highest governing body within shipping, the International Maritime Organization (IMO), yet but a few guidelines can be found regarding the engine room spaces. These are found in the Maritime Safety Committee´s (MSC) Circular 834 *“GUIDELINES FOR ENGINE-ROOM LAYOUT, DESIGN AND ARRANGEMENT”*. However, the only guiding information about the engine control design in the MSC Circular 834 concerns air conditioning, for the purpose of providing relief from high temperatures in engine-rooms for electrical equipment and personnel but offers no guidance on other design issues.

A report issued by the International Association of Independent Tanker Owners (INTERTANKO) demonstrated that IMO MSC Circular 834 does not include recommendations about engine control room design, function, or ergonomics (Lundh, Aylward, Mackinnon, & Man, 2017). Nor does there exist any Safety of Life at Sea (SOLAS) regulation for engine control room design as can be found for the bridge (SOLAS V, Regulation 15). How futile this is, especially considering that some watch-keeping engineers on vessels spend normally close to all of their working hours in an engine control room, becomes obvious. Furthermore, work in front of the computer within the ECR has increased tremendously with the current technological development. These few existing guidelines for engine room and ECR are not mandatory, which further complicates the issue of a safe working environment and operation for the vessel and its seafarers.

1.1 Purpose

The purpose of this paper was to investigate, from the crew’s perspective, what needs to be improved and standardized with regards to engine control room design, ergonomics, and function. This was done through focus group workshops with marine engineering students and marine engineers. The goal of the investigation was to propose recommendations based on these findings for rules and guidelines regarding design and construction of engine control rooms.

1.2 Research questions

- How does the engine crew perceive the work environment in the engine control room?
- What ergonomic consideration need to be taken into account to create a good work environment?
- Given existing control room designs, how would its operators redesign it for optimal ergonomics and function?

1.3 Delimitations

The study, which was based on workshops, was limited to Swedish marine engineers and Swedish marine engineer students. The number of engineers or students that attended the workshops may not be a sufficient source to come to a clear consensus about the research questions. A larger sample of the population of interest would be preferred to get a better understanding of the subject.

While there may be other persons being stationed in the ECR, such as chief, first, or electrical engineers, this study is mainly focusing on the second engineers/ECR operators and their work environment.

The current outbreak of the CoVid-19 virus has limited the ability to conduct interviews and workshops. The workshop had to be transformed to an online format which could potentially limit the discussion and creativity of the attendants.

2 Background and Theory

The focus of this thesis is on improving the design and function of the engine control room by recommending what needs to be implemented from a regulatory perspective regarding engine control room design. In order to provide recommendations as to how an ECR should be designed, the understanding of what kind of work that is expected to be performed there, and an understanding of ergonomics is essential.

2.1 Changes in the working routines of the ECR operator

The work in the engine department has changed from the more classic engine and machinery operating tasks all over the engine room to more administrative type of work, based primarily in the control room (Lundh & Rydstedt, 2016). With new environmental regulations and crew size optimizations, in addition to the engine monitoring and controlling duties, a considerable amount of administrative work has been added with logging of oil transfers, biofouling events, ballast operations etc. in record books, weekly and monthly logs, maintenance planning, bunkering documentation, and others (Heatherington, Flin, & Mearns, 2006; Olofsson, 2006; Wagner et al., 2008). This new type of work differs from the classic engineering duties. While the engineer is expected to perform these office duties, many control rooms still lack ergonomic working terminals, risking fatigue and harming the alertness of the engineer over the workday. The Swedish shipping industry have during the past decades experienced rapid technological development of vessels, harder economic conditions, along with reduced number of staff onboard. According to Swedish maritime engine department officers, this has contributed to several consequences, such as higher workload and alteration of work tasks. Furthermore, the lack of resources to handle these new changes and challenges have contributed to an even higher workload (Lundh & Rydstedt, 2014). Similar results were reported in another study completed by Lundh & Rydstedt, which focused more on stress (2010). This study, where 731 engine officers in the Swedish merchant fleet participated, showed that the high amount of stress perceived among engine officers does not necessarily come from the job content itself, but instead from an interactional perspective. The conclusions indicate that the fast-technological development, organizational changes, along with economic profitability pressure is the reason for the presumed stress (Lundh & Rydstedt, 2010).

2.2 Previous research

There has been an abundance of research regarding working conditions, ergonomics, safety, and social aspects on board ships. Although most research has been focused on the bridge team or the engine room areas, some research has also covered the engine control room. The following research and studies are listed to point out the need for improvement regarding the ECR. The INTERTANKO study in 2017 in particular is of interest; it highlighted the gap in regulations regarding the control room.

2.2.1 INTERTANKO

INTERTANKO is a trade association for independent tanker owners. In 2017, a study initiated by them used a data set to illustrate ergonomic issues in the engine department. It was analyzed and compared to the guiding instructions in MSC Circular 834. MSC Circular 834 *"GUIDELINES FOR ENGINE-ROOM LAYOUT, DESIGN AND ARRANGEMENT"* is an IMO non-mandatory guideline. The purpose of the non-mandatory guidelines from IMO (the MSC Circular 834), was to provide the shipping industry with information regarding engine-room safety and efficiency through design, arrangement, and layout of the spaces. The result of the study indicated that had the IMO-guidelines been mandatory for the engine spaces, most of the problematic areas end examples could have been improved from an ergonomic and design perspective. However, the results also showed guidelines and regulations regarding the engine control room design was lacking in MSC Circ.834. (Lundh, Aylward, Mackinnon, & Man, 2017).

The INTERTANKO report included approximately 250 examples of task performance and risks on board, collected by members of the association. These tasks and risks were related to the design, layout, and arrangement of the engine room. The purpose of the report was to evaluate whether the MSC Circular 834 guidelines had been applied. This was done with the data provided by INTERTANKO, to categorize the examples collected and according to the MSC/Circ.834 determine; (1) *"What are the problematic areas on board?"*. (2) *"If these guidelines had been fully applied, would these areas have been covered?"*. (3): *"Are there any gaps in the guidelines?"*. The five topics of guidelines from MSC Circular 834 are evaluated in the INTERTANKO report. These are: *"6.1 Familiarity"*, *"6.2 Occupational Health"*, *"6.3 Ergonomics"*, *"6.4 Minimizing risk through design, layout, and arrangement"*, *"6.5 Survivability"*. The results regarding the ER showed that in all categories, unnecessary risks caused by existing problems could help to be prevented by implementing proper, mandatory, guidelines for the various categories. Occupational health issues and physical ergonomics within the ER are still a large area of concern for the crew. Following the recommendations within the INTERTANKO report could reduce the risks involved in the work onboard. This is also applicable to the ECR, where proper, mandatory, guidelines on office ergonomics would create a better working environment. There is a gap in the implementation of proper ergonomic considerations regarding the ECR. According to the study, the guidelines within the specific circular (MSC Circular 834) should be in equivalence to those of a traditional office environment, with regards to the ambient prerequisite environment in an ECR. This is referring to physical ergonomics, lighting, noise, vibration, ventilation, and temperature; factors that may differ between the land-based, traditional office environment. This is why the information provided by the INTERTANKO report is of high relevance to this work. It shows the major lack of regulations, or even recommendations, on how an ECR should be designed and function. Furthermore, a conclusion from the study is that there is an existing lack of guidelines for ECR, which contributes as background to the idea for this paper.

2.2.2 Other research

In 2008 – 2009 a field study by Grundevik, Lundh, & Wagner investigated human factors in the engine control room. The study was based upon observations, interviews, and questionnaires amongst engine department employees. The study showed, amongst other findings, that the design of the modern ECR did not support the work of the operator, along with that administrative duties have increased. Already established guidelines, rules, and regulations, such as The American Bureau of Shipping's (ABS) guidance notes *"The application of ergonomics to marine systems"*, are often not adhered to. Several recommendations on how improvements could be made are presented, as the growing issues of the ECR are explained.

In a qualitative study Lundh et al. studied how the demanding working environment affected the engine room personnel on board Swedish merchant ships. The study showed that the design of the ECR and ER are crucial to how the work is carried out. The study also showed that inappropriate design of the spaces leads to risk-taking actions by the personnel (Lundh et al., 2010). This work was followed up by Lundh's Doctoral dissertation which explored the crews' abilities to adapt to the evolving work situation on board Swedish merchant vessels. These work situations contained both technical and sociotechnological advancements, as well as other factors like culture and higher pressure from fewer manning and higher demands of profitable work. The result indicated that engine crew, and especially engine officers, had to adapt to a suboptimal prerequisite in order to complete their tasks, as ergonomics was not considered in the design of the ER and ECR (Lundh, 2010).

The lack of regulation and IMO guidelines supporting the design and layout of the ER and ECR have been cited as a problem in previous research. In a research article by Mallam & Lundh the general lack of IMO guidelines regarding the ergonomics in the engine control room in contrast to the general engine room design was highlighted. The analysis showed a disconnection between regulations that specify design criteria, and the criteria which enhance competency training and safe operation. From a regulatory perspective, ECR design does not support the operation in the ECR, and once more, the conclusion drawn from the article is that the only way to ensure work environment improvement in the control room is through mandatory regulations (Mallam, & Lundh, 2013).

In 2015, research on how ergonomic features in a control room environment affects the operator's alertness and comfort was carried out by the Department of Product and Production Development at Chalmers University of Technology, Gothenburg. The study showed that a high-end control room, compared to a traditional control room, had significantly improved operator productivity, alertness, and overall wellbeing. However, the high-end control room caused increased pressure on the operator to perform well (Osvalder, Andersson, Bligård, & Colmsjö, 2015).

The same year, Simonsen & Osvalder released a paper where the aim of the study was to *"identify a foundation for evaluation measures, i.e. to find aspects of the control room system* *that contribute to safe operation from a human factors perspective"* (Simonsen, & Osvalder, 2015). This study contains information about what operators and other technical personnel considered important regarding the control room, and how the human interaction with the control room can be improved to ensure safe operation. A control and alarm system that aid the operator by helping decide what task that need to be prioritized, providing trends to help backtracking or predict data, offer the right amount of information for any given situation, and abilities of controlling the plant as a whole from the control room alone (without having to move out into the machinery areas) were some examples of properties sought after to improve the safety of the plant and its personnel.

Other research has shown that the ECR work environment, and the design, has an impact on the operator's performance (Lundh et al., 2011; Wagner et al., 2008). These results showed that the operator's ability to easily overview information and data in the control room area, along with inefficiently placed arrangements and designed work nodes, were the largest issues. This contributed to increased physical separation and worsened communication within the ECR. The increasing computerization, and the lack of ECR design to match the evolvement, was specifically pointed out. The growing gap between technological advancement and the continuously traditional design may also pose a threat to safety of the ship and crew's performance (Mallam & Lundh, 2013; Wagner et al., 2008).

2.3 Ergonomics

In order to provide recommendations as to how an ECR should be designed, an understanding of ergonomics is essential. The word ergonomics is derived from the Greek words *"ergos"*, which means *work*, and *"nomos"*, which means *study of*. The field of ergonomics studies how well people work and function in their environment. The short description of ergonomics would be that a task should be fitted to a person, and not the other way around. Ergonomics is focused on achieving a way to improve, or maintain high performance, efficiency, safety, and comfort while work is performed. A description by Ergoweb Inc. is quoted: *"The science of work. Ergonomics removes barriers to quality, productivity, and safe human performance in human-machine systems by fitting products, equipment, tools, systems, tasks, jobs, and environments to people."*. Ergonomics includes basically all that has to do with human to machine interaction, human to system and human to process interaction. Examples are working position (posture), thermal exposure, noise, vibration, stress-factors, as well as organizational matters. Ergonomics can be divided into three subcategories: *physical*, *cognitive*, and *organizational* (White, 2008).

Physical ergonomics is based on how a person responds to both physical and physiological stress. The anatomy, physiology and biomechanics of a person are considered and accounted for when performing physical activity. In physical ergonomics, office ergonomics is an important aspect to take into consideration (White, 2008). Office ergonomics can be divided into two sections, (1) physical condition, abilities, and limitations; and (2) the ambient environment. Office ergonomics generally includes working posture, work style, activity/task; and ambient environment factors include, lighting, air quality, noise, and vibration. Awkward arms/hands posture, repetition of motions, design of the workstation, furniture selection, staffing and work schedule are also important when it comes to creating an ergonomically adapted work environment (Chim, 2014).

Posture is defined as the position of the body when a task is carried out. Awkward posture imposes an increased risk of acquiring injuries, such as musculoskeletal disorders. The joint deviates from a natural position, and the more the position deviates from the natural stance, the higher the risk of injury. Posture related injuries can be acquired from bending, twisting, or simply to sit in a working position for an extensive amount of time. In office ergonomics, where posture is not typically associated with a heavy physical exertion, factors such as wrist flexion/extension, shoulder abduction/flexion, hand positioning, neck flexion or constant pressure on lower back poses large problems in the office environment. Combining a bad posture with static exertion on the body over a duration of time is something which should be considered when creating an ergonomically adapted control room (Ergoweb, 2010). The layout and design of an office environment affects how the worker can perform given tasks, e.g. if the office has a sit-stand terminal/desk, the worker has the ability to choose whether he/she prefers to sit or stand. Another example is adjustable chairs where the back of the chair can be bent backwards if the working terminal requires the operator to "look up"; this to avoid an awkward posture with potential of injuring the neck (the cervical spine). Posture should be matched with the task to avoid improper posture/working positions. Work Related Musculoskeletal Disorders (WMSDs) among office workers, who are spending most of their time in front of computers, is a growing issue. Working in front of a computer is also linked with experiencing visual discomfort, with symptoms such as blurriness, difficulty in maintaining focus and eyestrain. Research has shown that through the combination of office ergonomics training, along with a sit-stand workstation, improvements can be made. A study focusing on physical ergonomics and specific interventions showed that musculoskeletal issues and visual discomfort of office workers were decreased through the combination of sit-stand work stations, and ergonomics training leading to an increase in performance of the work tasks (Robertson, Ciriello, & Garabet, 2013). The increased use of computers in office spaces and maintaining the same position for longer periods of time has elevated the risks of injuries. This has made office ergonomics an even more important topic to consider in a workplace and can lead to an overall healthier workforce with less sick leave and higher productivity (Chim, 2014).

The second part of office ergonomics in relation to physical ergonomics is the ambient environment which focuses on factors such as lighting, air quality, noise, temperature and vibration in a work environment. A brief description from Ergoweb (2010) of the various factors and potential exposure risks are presented, starting with temperature. A comfortable temperature is essential in a work environment. Extreme temperatures can lead to heat stress, or cold stress. Although the temperature in the ECR is never an extreme, the surrounding work environment, the machinery spaces, can significantly vary. Heat stress is the total heat load that the body is able to handle, which is generated from the ambient environment and internally from the workers metabolism. Heat stress may lead to heat stroke, a serious condition which can be fatal. A less threatening condition when exposed to excessive heat is heat exhaustion, heat cramps, and various disorders such as dehydration, loss of physical or mental work capacity. Cold stress, on the other end of the spectrum is the opposite, where extreme cold can lead to severe consequences for the human. Cold stress is caused by exposure of a cold temperature, which lowers the body's core temperature. This can result in shivering, reduced consciousness, reduced coordination, ventricular fibrillation, and in extremely severe cases it can, just as heat stress, be fatal (Ergoweb, 2010). The temperature in the ECR is therefore very important to take into consideration when designing the ECR. The ECR can function as a relief from the temperature of the ambient environment in the various other workplaces of the vessel, usually the engine room. Although this may seem exaggerated, one should remember that vessels travel all around the world, where the outside temperatures can vary from extremely hot to extremely cold, and the engine room is often times too hot to work in for an extended period of time.

Vibration, or whole-body vibration, has been proven to be a risk of injury. The dose of vibration that the individual is exposed to increases the risk of injuries, such as back pain. Vibrations can, apart from creating injuries, disrupt/reduce the concentration of an operator in a working environment (Ergoweb, 2010). In the ECR, this is relevant with regards to the positioning of the ECR in the vessel.

Lighting, measured in *"lux"*, is also of importance to a working environment as various tasks require different amount of lighting. The recommended in office lighting is to have sublime background lighting with between 300 to 700 lux. Work that requires more lighting, such as high visual sensory perception and contrast sensitivity, requires approximately 1000 to 10,000 lux (Ergoweb, 2010). In the ECR, where there is rarely any normal daylight from the sun, proper lighting is a necessity. Positioning of lighting is also relevant, as reflection in computer screens can cause disturbance for the operator. Noise, defined as unwanted sound, can be a constant disturbing factor in the ECR. This can appear as a repetitive sound from an engine, or of any other system, or a high frequent sound which penetrates the working environment. Exposure to noise can cause loss of hearing, difficulties concentrating, tinnitus, deafness, or speech misperception. The longer the duration that the human is exposed to noise, the greater the risk of suffering consequences from this (Ergoweb, 2010).

The goal of office ergonomics is to both understand and address the given factors to try to obtain the optimal level for human functioning, comfort, safety, and productivity of personnel within a given work environment. Properly implemented office ergonomics can therefore lead to increased effectiveness, efficiency, and productivity. Research has shown that an uncomfortable or dysfunctional environment, which is not adapted to individuals working, is associated with a higher risk of injuries. Creating a comfortable and pleasant environment for the worker and fitting the task to the person can substantially reduce this risk (Chim, 2014). Office ergonomics evidently applies to the shipping industry as well, where the ECR has become a rather similar environment to the one in a normal office landscape. The expected tasks involved in the ECR are also often of the administrative type, similar to that in a regular office. Potential adjustments of the ECR with regards to office ergonomics is also discussed in this thesis.

The second branch of ergonomics, cognitive ergonomics, refers to the human cognitive abilities and limitations. It focuses on how well suited a task, a machine, or the environment is to the human's performance. Cognitive ergonomics relies on the perception, the reasoning, the motor response, and memory of the human. There can often be a gap between the human and the machine, system or process they are working with which impacts how a human perceives, remembers, and makes decisions regarding information presented. The processing of information does not function the same in a human as in a machine. The human perceives information through senses, signals to the brain, which leads to action taken, whilst a computer functions out of system components. Additional aspects of cognitive ergonomics include learning, decision making, individual differences, selection of action, mental workload and the stress of the human. Understanding and improving the relationship between human and system or environment, could be considered the aim of cognitive ergonomics (Wickens, Hollands, Banburry, & Parasuraman, 2013). When it comes to the shipping industry and cognitive ergonomics, the functionality of the alarm system and other various automated systems, and its interaction with the operator(s) in the ECR, are of high relevance (Lundh, 2010). As previously written, the increase of computers in the ECR can have effects on physical ergonomics, but also on cognitive ergonomics. From a cognitive ergonomics perspective, it relates to how the human perceives the information presented by the computer, how this is managed and how it affects the operator. The design and layout of the ECR is another aspect which impacts both the cognitive- and physical ergonomics considerations within this paper. How to improve the relationship between human and machine is a relevant point in cognitive ergonomics, which will be slightly explored in this thesis, within the field of the ECR.

A well-known construct within cognitive ergonomics, *situation awareness* may be described as *"the sum of operator perception and comprehension of process information and the ability to make projections of system states on this basis"* (Kaber & Endsley, 1998). The importance of operator situation awareness regarding control rooms is crucial as it directly affects the outcome of the operator's actions based upon what he or she perceives from the operator panels. Furthermore, team situation awareness, which similarly can be considered the sum of the personal situation awareness' of a collaborating team's members, is relevant to ECR designs considering that in some cases there may be multiple operators active in an ECR (Kaber & Endsley, 1998). Older control rooms used large analogue panels and gauges in a way that generally was easy to comprehend for the whole control room crew. Today, most of these analogue instruments are replaced by computerized terminals which might offer good flexibility in data presentation but could also detract from a good overview of machinery status, especially for multiple operators, if not designed properly (Lundh, et al 2010). Large screens with useful data mounted at easily visible locations could potentially improve the machinery overview for the engine crew. A study on how team performance measured by the team situation awareness can differ between a traditional nuclear power plant control room versus an advanced computerized control room showed a generally better team situation awareness in the modern control room versus the traditional one (Seung, Ar, Jinkyun, Hyun, & Poong, 2016).

The third and final branch of ergonomics is the organizational ergonomics. It focuses on processes, organizational structures, policies and how to optimize these. The interaction within an organization, how the work is divided, how communication is handled and the general teamwork in the organization is the base of this branch of ergonomics (White, 2008). Organizational ergonomics can play a major part in the well-being of the operators and how the work style and tasks are handled. However, this thesis will not focus on this branch of ergonomics, as it is not considered to be within the scope of this paper.

2.4 Laws, regulations, and standards

For any type of job, a worker needs an ergonomic working environment in order to perform in a safe an efficient way with minimized risk of injury, fatigue, or lack of vigilance. There are several legislative areas governing workplace ergonomics and safety, stretching from international to national to independently recognized standards regulations, and guidelines. The international regulations from IMO are very thin regarding engine control room design but are more extensive when dealing with bridge design. Knowledge in this field is however available if contacting and consulting ISO (The International Organization of Standardization). Swedish national work environment laws are more extensive but still relatively unspecific.

2.4.1 IMO: SOLAS V Regulation 15 & MSC Circular 982

The highest governing international body of shipping is IMO and in SOLAS Chapter V they list several requirements for safe operation of a ship. Regulation 15 *"Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures"* as the name states specifically deals with bridge design from several aspects. Amongst other bullets it is stated that *"…the design and arrangement of navigational systems and equipment on the bridge and bridge procedures* shall be taken with the aim of: …*

1.3 enabling the bridge team and the pilot to have convenient and continuous access to essential information which is presented in a clear and unambiguous manner, using standardized symbols and coding systems for controls and displays;

1.4 indicating the operational status of automated functions and integrated components, systems and/or sub-systems;

1.5 allowing for expeditious, continuous and effective information processing and decision-making by the bridge team and the pilot;

1.6 preventing or minimizing excessive or unnecessary work and any conditions or distractions on the bridge which may cause fatigue or interfere with the vigilance of the bridge team and the pilot; and

1.7 minimizing the risk of human error and detecting such error if it occurs, through monitoring and alarm systems, in time for the bridge team and the pilot to take appropriate action."

The * refer to the MSC Circular 982 *"GUIDELINES ON ERGONOMIC CRITERIA FOR BRIDGE EQUIPMENT AND LAYOUT"*.

Regulation 15 clearly states that bridge design shall be arranged in a way that makes it easy and convenient for the bridge crew to see and obtain all necessary information (bullet 1.3 & 1.4) so that the team can be allowed for effective decision making and minimizing the risk of human errors thereof (bullet 1.5 & 1.7). 1.6 state that the bridge design should be ergonomically well designed to minimize excessive or unnecessary work, distractions, or other vigilance lowering properties that will cause fatigue or lack of vigilance of the bridge team. The scope of MSC Circular 982 is stated as following *"The Guidelines are developed to realize a successful ergonomic design of the bridge and the equipment on the bridge, which will improve the reliability and efficiency of navigation. These Guidelines therefore contain ergonomic requirements as well as a functionally oriented bridge layout to support watch-keeping personnel in their tasks by a user-centred [sic!] design of the bridge equipment and layout."*. Following are clear definitions of each workstation on the bridge, such as a *"workstation for navigating and manoeuvring [sic!]"*, *"workstation for monitoring"*, etc.

Furthermore, a proposed layout of a bridge is provided in the circular as can be seen in figure 2.1. The required field of view for each (navigational, lookout, and monitoring) station is specified both for horizontal and vertical view. In this manner the circular continues to list a comprehensible number of ergonomic parameters such as lighting, frame spacing of windows, access ways around the bridge, optimal positions for each station, temperature and humidity, viewing angles of the operator consoles, console height, alarm handling and properties etc. Overall, this circular gives clear and detailed requirements of how the bridge shall be designed. A comprehensible amount of these points could be considered equally important when designing engine control rooms. However, no such regulations for control rooms exist in SOLAS and the MSC Circular 834 does not handle the engine control room in any way comparable to how MSC Circular 982 governs the bridge design. However, it has been argued, as the work in the ECR show many similarities with that on the bridge, that the requirements in SOLAS V/15 could be applied to the engine department. Mandatory requirement promoting the team performance, communication and information processing is believed to benefit the design and the function of the ECR (Ivergård & Hunt, 2009, Chapter 9).

Even though the SOLAS V Regulation 15 and MSC Circular 982 today are aged documents (MSC Circular 982 dating back to 20th December 2000, and SOLAS V Regulation 15 to 1st July 2002) the design and ergonomic guidelines are in many ways still viable today. They do however not take modern computerized workstations into consideration since these were not as common when these documents were written. It could be argued that these guidelines could be updated to full modern standards.

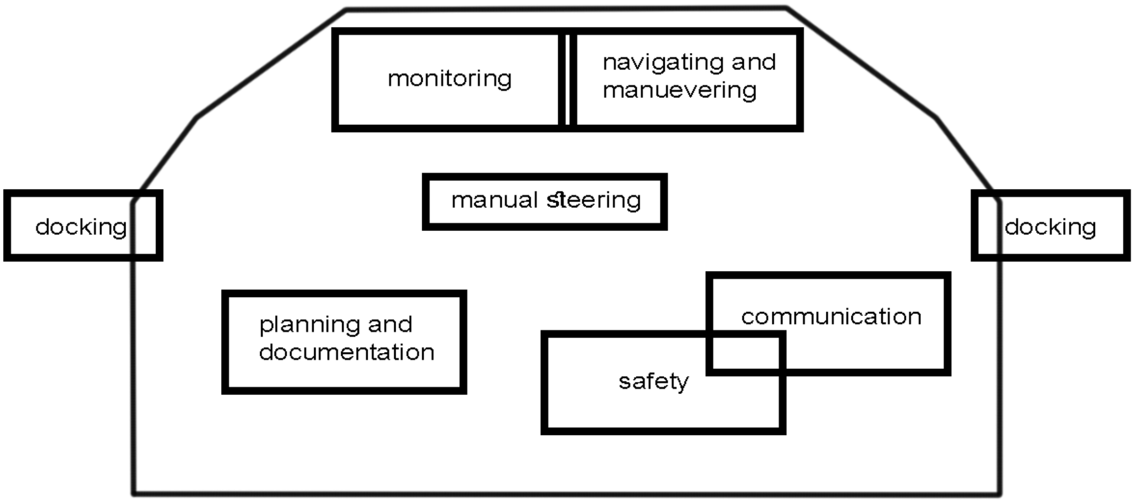

Figure 2.1, proposed layout of a navigational bridge based on the MSC Circular 982 by IMO.

2.4.2 ISO Standard

There are extensive available knowledge and guidelines regarding control room design. ISO is a worldwide federation of national standard bodies. They publish standards named *"ISO"* followed by an identification number that organizations can certificate themselves under. In ISO 11064, information is provided regarding ergonomic requirements, recommendations, and guidelines for control room layout. ISO 11064-3:1999 *"Control room layout"* is the section of the ISO standard that is relevant for this thesis. The section aims to provide the user with a more suitable interface and working environment. This is assumed to result in solutions which shall minimize error and enhance productivity. This part of ISO 11064 is primarily intended for stationary control centers, however, it is stated in the document that the principles could be relevant/applicable to mobile centers, such as those found on ships (International Standard 11064-3:1999).

2.4.3 Swedish work environment law and authority regulations

For ships sailing under Swedish merchant flag these are Arbetsmiljölagen, (SFS 1977:1160), the Swedish Work Environment Authority's Statute Book (AFS) and The Swedish Transport Agency's Statute Book (TSFS). These regulations contain guidelines of how different types of ergonomic parameters should be designed; adequate lighting, working heights, aids for heavy lifts, protection against monotonous moves and duties amongst many others.

Arbetsmiljölagen (AML, SFS 1977:1160) does cover ships operating under Swedish merchant flag both in and outside Swedish territorial waters (SFS 1977:1160, 1 Ch, 2 §). However, this law does not list specific demands but rather provides more general statements such as *"4 § De arbetshygieniska förhållandena när det gäller luft, ljud, ljus, vibrationer och liknande skall vara tillfredsställande." ([authors own translation] "4 § The working conditions relating to* *air, noise, lights, vibrations and similar shall be fair.”).* Instead, the Swedish Transport Agency’s Statute Book (Transportstyrelsens föreskrifter om arbetsmiljö på fartyg (TSFS 2019:56) governing the working environment on board Swedish merchant vessels goes to some extent deeper in their definitions of acceptable working conditions. In general, it does in many cases make understood that the publications of the Swedish Work Environment Authority (such as AFS 2012:2 Ergonomics for the Prevention of Musculoskeletal Disorders) also applies at sea. Hence the authority does not generally differentiate between workplaces ashore and onboard unless specifically stated.

2.4.4 Class regulations

A search has been conducted in DNV GL, Lloyds Register, and Swedish Club’s classification documents. It is clear that classification societies have rules and guidance covering physical, cognitive, and organizational ergonomics applicable to almost all other parts of a ship, except for the ECR. The only relevant document found has been *“DNV GL RULES FOR CLASSIFICATION Part 6 Additional class notations Chapter 8 Living and working conditions”* that states regulations to certain comfort parameters such as noise & vibration levels, temperature ranges, and air velocities for *“machinery control rooms”*. However, no regulations about terminal ergonomics or data presentation can be found. (DNV GL, 2015)

The American Bureau of Shipping (ABS), a classification organization based in the United States, has created guidance notes on *“The application of ergonomics to marine systems”*. These guidance notes provide information applicable to several workspaces within ships, where the control room is a major one. How to implement proper ergonomics in the ECR can be found in this document, ranging from design of human to system, to workstation design for optimal ergonomics (ABS, 2013). Important to remark regarding this document of ergonomics application is that it is not mandatory regulations, but only serve as guidelines for how ergonomics can be applied in the marine systems. These guidance notes will be further discussed in the discussion, with regards to the information gathered from the focus group workshops on what is important to take into consideration according to the participants of the workshops.

3 Methodology

This study adopted a qualitative research approach to data collection and analysis. The qualitative research method consists of a set of interpretive material practices, and focuses on understanding the experience, perspective, and thoughts of the participant of a study. Normally for this research method, the interaction among participants of a study is of high priority, and the researcher is not bound to specific expected results, which results in a flexible and open research format. As opposed to quantitative research method, qualitative research is described as inductive, meaning that the researcher may form a hypothesis from information provided by participants of a study (Harwell, 2014).

The means of collecting data was through workshops in the form of focus groups. A focus group can be defined as an informal discussion within a group of people that possess relevant information regarding the chosen topic. It includes more than one participant for the data collection, and a usual group is of around six people. It can therefore be defined as a group interview, however there are differences. Group interviews can be of participants with different knowledge and experience in the discussed topic, whilst in a focus group, the participants are carefully chosen as they are expected to possess specific knowledge on the topic which is to be discussed. The main aim of a focus group is to understand and describe interpretations of the participants of the study, to gain a deeper understanding of the chosen topic. Participants are guided by a moderator who asks questions, but let the conversation be an interaction in between participants. The participants are leading the interaction, rather than the researcher, which allows of a wider, not as strict, discussion. The aim is not to reach a consensus regarding the topic, but rather to find a range of responses with various opinions or perceptions of a situation/topic. This method is seen as a way of achieving results quickly and efficiently (Liamputtong, 2015).

The focus group workshops were recorded and transcribed, and data collected was interpreted and used with a thematic analysis methodology. Thematic analysis is an analysis methodology which offers a highly flexible, comprehensive, and accessible way of analyzing qualitative data. This method enables the investigator/author to easily look for patterns in the data, and then analyze it through a coding process. It relies on a thorough familiarization with the data collected, to be able to find patterns of interest. It is therefore a highly useful method to apply when analyzing larger qualitative amounts of data via e.g. interviews. The article "*Using thematic analysis in psychology*" was selected as a primary source for data analysis as it provides a step-by-step guide through the phases of thematic analysis, allowing the researcher to approach and work with the data in a structured way. As the data has been collected, the author looks for patterns and initial codes. Once codes of interest are found and defined, the writer can create themes out of the extracted data patterns. As themes are formed, the themes are named, defined, and adapted to create possible heading themes and subthemes. The final step is relating back to the analysis of the research question, so one can form a report of the analysis (Braun, & Clarke, 2006).

The original plan for the data collection was through physical interviews with actively working marine engineers, marine engineer students and with a naval architect. The outbreak of the COVID-19 virus limited the possibilities of both interviewing and conducting physical workshops with focus groups. Based ono the social distancing recommendations, the primary method was instead completed using online workshop sessions held with senior students at the marine engineering program at Chalmers University of Technology. Through a voice and text chat platform, the application *"Discord"*, with the ability to record the workshops, participants were asked in a semi-structured way to reason and discuss the engineers work in the control room, ergonomics, and to develop a control room based on their own experience from e.g. their internships on-board and work ashore if applicable. For detailed description of how the workshops were conducted, see *"3.4 Data collection – workshop"*. Based on the interpreted data, recommendations regarding design and construction of engine control rooms were developed.

3.1 Participant recruitment

Selective recruitment, also known as purposive sampling, was the strategy used to find and recruit the participants. The selective recruitment is based on that individuals with certain skillsets, knowledge or experience are of relevance to a study (Silverman, 2011). The criteria for eligible participants was relatively broad, considering that the interesting parameter is the ergonomics of the control room. Therefore, the baseline criteria to participate in the focus groups was any engineer or engineering student who had some experience working in a control room either ashore or on-board. It would have been positive to get a good mix of physical characteristics, with both male and female participants since ergonomic preferences differs with different body- and mind characteristics. For this study, Senior marine engineer students and one actively working marine engineer were recruited to participate in the focus group workshops. The participants were selectively recruited through contact via social media platforms and by previous existing connections to the authors.

3.2 Participant demographics

In the beginning of each workshop, a demographic survey was completed as participants presented themselves with their age, sex, and experience in the field. A total of 11 participants enrolled in the workshop. 10 of these were senior year marine engineer students, and one participant was working as an engineer onboard a cruise ship. The participants were between 22 and 47 years old, with a mean age of 26.5 years, and a standard deviation of 6.76. All 11 of the participants were male. Participants were asked how many engine control rooms they had worked in, and the response was in between 3 to 15 for the students, with an approximate average of 6 ships (ECR's) amongst the students. The actively working marine engineer had much more experience, around 10 years. The various ECR that the participants had worked in was on all different kinds of vessels, ranging from tankers, passenger ships, ice breakers, to cargo ships.

3.3 Research ethics

Prior to the beginning of the workshop, participants were given a consent form which informed them of the study and the terms of their participation. This form was included along with the information of the workshop and the thesis. In the consent form, participants were informed that they could at any time cancel their participation and the information shared would then be deleted. Anonymity was guaranteed in the project and data collected would be presented without connection to vessel, person, or shipping company. Participants therefore had time to read and reflect upon the study and pose questions to the moderators, prior to starting the workshop.

3.4 Data collection - Workshop

Data gathering was conducted through focus group workshops. To provide a common understanding of the topic, prior to beginning the workshop participants received information on the study, basic ergonomics, the workshop, and the consent form. The workshop began with a brief introduction to ergonomics, going through the material handed out and complimentary explanation of the material when requested. This was to enlighten the participants about the context, purpose of the study and achieve a common level of knowledge regarding ergonomics and information on the research questions for this thesis.

The online sessions were conducted in smaller groups of 3-4 participants in each focus group. This to avoid congestion of thoughts and creativity using the narrow platform of voice chatting. A total of three focus group workshops were conducted. There were two groups of four people, and one workshop group with three participants. All sessions were recorded for improved data analysis, and then later transcribed. The workshops with senior marine engineer students were held online through the application *"Discord"*. The workshop focused on the ECR, with regards to the research questions which were to be answered in this report. These three questions are found under *"1.2 Research Questions"*. With these three research questions as main focus for the workshop, several different sub-questions were asked to continue and potentially widen the discussions with relevant input from the moderators. Example for the first research question: *"how does the engine crew perceive the work environment in the engine control room?"*, participants were then asked a sub-question: *"Do you feel that the design of the control room aids for a safe operation both in normal and extreme scenarios?"*. Different sub-questions were used for the different workshops, as the aim of the moderator was to not interfere with the discussions, but simply to provide further suggestions on what could be discussed with regards to the research questions. The reason for this was to make sure we had covered as much as possible within the area of the question presented, and to minimize the risk of missing valuable information. This same method was applied for all three research questions. All the sub-questions that were asked, and those prepared to potentially have been asked, are to be found in the appendix of this paper. The final task in the workshop was showing a template of an existing engine control room, the aim for the participants was to redesign the ECR to their preferences of what is important, i.e. research question III. The workshops allotted for approximately 20 to 30 minutes for each of the three research questions. This resulted in workshops of approximately 1.5 to 2 hours each, which is a normal duration for this kind of focus group interview.

4 Results

From the data collected and analyzed, sorted under each of the three research questions a total of eight main themes and eleven sub-themes could be identified. For some of the themes no deeper sub-themes were found. They are presented briefly under each research question in table 4.1 – 4.3 and further in-depth after.

Table 4.1. Research question I with identified themes and sub-themes.

1. How does the engine crew perceive the work environment in the engine control room?	
Theme	**Sub-theme**
1.1 Mismatch of functionality - Work has changed but the ECR has not	-
1.2 Lack of prioritization and standardization in design and construction	-
1.3 Working conditions	**1.3.1** Regular operation **1.3.2** Critical/raised manning operation

Table 4.2. Research question II with identified themes and sub-themes.

2. What ergonomic consideration need to be taken into account to create a good work environment?	
Theme	**Sub-theme**
2.1 Ambient environment	-
2.2 Physical ergonomics	**2.2.1** Layout and system overview **2.2.2** Office ergonomics
2.3 Cognitive ergonomics	**2.3.1** Design **2.3.2** Alarm systems **2.3.3** Traffic through ECR and other disturbances

Table 4.3. Research question III with identified themes and sub-themes.

3. Given existing control room designs, how would its operators redesign them for optimal ergonomics and function?	
Theme	**Sub-theme**
3.1 Tanker ECR	**3.1.1** Commonly identified issues **3.1.2** Proposed changes
3.2 Cargo ship ECR	**3.2.1** Commonly identified issues **3.2.2** Proposed changes

4.1 Research question I - How does the engine crew perceive the work environment in the engine control room?

The opinion was unison amongst the workshop attendants that the ECR is not generally adapted to the type of work expected to be undertaken by its operators. The expected tasks of the operator today have shifted more towards office related work with increased levels of documentation and reporting, and less of the traditional engineering duties. Furthermore, the ECR was perceived as a low prioritized area. The consensus was that the ECR was *"something stuffed into the ship where space permitted"* and little consideration given to location or design. This was pointed out by every group as a quality issue.

4.1.1 Mismatch of functionality - Work has changed but the ECR has not

The expected tasks performed by the ECR operator have shifted towards more office desk work according to all the workshops. Contradictory to this, it was suggested that older ECR's generally had more and better desks for office work, while newer ECR's tend to have less office spaces and operators seems to be expected to perform their office work sometimes at the control panels. This was described by all groups as problematic as the control terminals still today are of the old machinery terminal style which are bulky, not adjustable, and typically slanted, meaning that your items (i.e. papers, pens, calculator) continuously fall off the desk. In other words, anything but ergonomic. A common view amongst the participants was that engine crew often just accept the customs of their ship and ECR, not really questioning ergonomics or working conditions.

Although not specifically asked to all groups, one group agreed on that the duties of a general workday in the ECR consists of 50% office work, 30 % surveillance, and 20 % system maneuvering. The discussion of the other groups supported this idea of office work being at least 50 % of the ECR work. The type of vessel has a great impact on the duties of the ECR operator should be noted; on smaller tankers the operator may undertake more engine room duties whilst on a cruise ship the operator may not be allowed to leave the ECR at all during his or her watch. The major changes were described to be mainly a shift from system surveillance (that is to a greater extent being controlled by computerized systems today) towards an increase in required office work. New regulations and policies require comprehensive logging and documentation in record books, weekly or monthly company reports, bunkering papers, or work order preparations.

"[authors own translation] The workload [in ECR] is steadily increasing. There are more demands of documentation, a lot more if it is anything environmental, so the office type workload has increased heavily. […] I cannot really remember the last time I actually tinkered with something the last time; I do not have any time for that. If we are to do some sort of work I [as an engineer working in the ECR] must make work orders, safety analysis of the work to be done, and get the required permits. The paperwork itself may take up to 4 hours before I can even send my men to work."

Even though the participants described some general improvements with newer ECR's compared to older ones such as better lighting with daylight fluorescent or LED lights getting installed, their opinion was that most of the major ergonomic issues are still left unattended. The bulky, non-ergonomic control panels with chairs of highly varying quality are still present and office spaces are more rather getting fewer and worse in design, than improving. One participant explained and showed a picture from a cruise company depicting how they as a company are developing the ECR's in their own newbuilds. The key point was that the cruise business is taking design into their own hands to develop the ECR's without involving the IMO, and the focus on improvement lies entirely on security and safety aspects, and still very little consideration for ergonomics. When asked if he considered this newer ECR design to having adapted to his expected work tasks he stated a clear *"no"*.

"[authors own translation] My working area consist of a bulky steel terminal with two keyboards, my food in between them if I need to eat, to the right I have the logbooks, and far right my work PC. This space is my designated workspace and it is not ergonomically adapted to my work tasks at all. It's not like an office desk in any way. Height of benches, screens etc. is totally off. After a six-hour duty shift you have pain in your shoulders and neck and your body feels stiff."

4.1.2 Lack of prioritization and standardization in design and construction

Participants described a feeling of the ECR not being a prioritized area during the design and construction of the ship. New panels or cabinets are often patched into the ECR to fix problems that could have been rectified with a better design from the beginning such as grouping together related controls and avoiding mixing too much analogue and digital systems that may work poorly together. A thorough, complete whole ECR design was asked for, not a patchwork of different solutions, sometimes added after a long time.

Unlike bridge terminal layouts and designs who have concrete guidelines in the MSC Circular 982, the layouts and designs of ECR terminals lack similar type of standardizations. This was described to lead to longer familiarization periods for each new control room and varying ability for good system overview and workflow. The ability of getting a good overview of the systems was described as often unnecessarily complex, e.g. by lack of large overview screens showing important data. If the engine alarm goes off and the engineer is working out in the engine room, he or she need get back into the ECR and instead of instantly getting a good situation overview the engineer might have to dive down into several computer screens to investigate the cause.

> *"[authors own translation] My general thought is that there isn't any structure about where everything is, you have to relearn every new panel every time. Often spread out, you can rarely stand in one place and see everything, you often must run around. Don't know if that is good or bad, but as an example, sometimes aren't all the auxiliary engines panels at one place next to each other and boiler panels can be in an entirely other spot like 8 meters away, and pump start and stop buttons are far away. So the overview is rarely good from one position."*

A clear consensus related to if older analogue panels or modern computer screen-based panels provides the best design for overview ability and maneuvering could not be established, since there was no uniform view on "old or new" design. As described above under *"4.1.1 Mismatch of functionality - Work has changed but the ECR has not "* the cruise business were described as at least trying to rectify some of these layout design flaws on their own, but generally to for the purpose of improving safety of operation, and not really improving the ergonomics.

4.1.3 Working conditions

The type of ship generates different working conditions. A passenger ship with several standbys each day require the engineer to spend more time in the ECR and at its terminals than a cargo ship going on trips spanning over several days with periodically unmanned ECR's. The work groups described this as possibly being taken into consideration during ship design since passenger ships were generally described as having better ECR's than smaller tankers or bulk ships.

4.1.3.1 Regular operation

For regular operation most of the ECR's were described as single manned except for cases where the first and sometimes the electrical and chief engineer also had their offices in the ECR. The groups depicted having too many offices inside the ECR as not optimal, both considering the lack of office ergonomics and because of the disturbing factor between both the ECR operator and the engineers at their offices. If the operator is doing some thought-heavy documentations it could be very disturbing if e.g. the wipers or fitters were running in and out of the ECR to speak with the first engineer about some undergoing work. The same disturbing factors with traffic in the ECR were discussed more deeply under research question III regarding coffee rooms and toilets placed inside the ECR. There were mixed opinions about this, but a general consensus was that it could be ok for smaller ships but not for ships with larger crew because it could crowd the ECR up and cause unnecessarily traffic. The toilet in ECR was also described as an issue for the operator's wellbeing if bad smells would originate there.

4.1.3.2 Critical/raised manning operation

This sub-theme was described by the participants as highly dependent on the ship type. On ships with smaller ECR's it can easily become too crowded in the ECR when situations arise. People stand on top of each other and block the pathways or terminals to hamper movement and workflow. As a contrast, modern cruise vessels were described as having very good and open ECR designs to aid in emergencies with a structured role placement of crew and their dedicated terminals. As a middle ground between these, ferries were described as a very mixed experience. Some ECR's were described as spacious and good when higher manning was needed, while some other where stated as not good at all. The common denominator in all cases was the available space, smaller ECR's simply provide less space to move in. This sub-theme highlighted the lack of standardization of ECR layouts by addressing the vast mixture of experiences of how well the ECR's worked in these elevated operational modes.

One workshop group was asked if they had observed any specific safety manning schemes for emergency operation other than the regular fire or man overboard safety groups, and if they thought that would make them feel more safe and secure in their duties as the ECR operator. No one reported to have seen this on board, and they all argued that it could be a good thing if they knew that everyone had a designated terminal and/or responsibility in case of emergencies; it could act as a motivator to inspire the crew members to take greater responsibility and learn more about their designated areas. At the same time, it was argued that the roles should be more of a framework to lean back on, as flexibility among the crew is still important to avoid scenarios where the only one with knowledge about a certain system or procedure is unavailable.

> *"[authors own translation] One ship I was working on had a fuel pump hanging, the exhaust gas temperatures rose quickly so we had to shut down that engine. The ECR was kind of small so it got a bit intense from the start when the chief, first, and second engineer came in and made it really crowded. People ran upon each other and in addition to this, the watch going personnel had to come in and get instructions etc."*

4.2 Research question II - What ergonomic consideration need to be taken into account to create a good work environment?

Looking at ergonomics from all perspectives, the participants were asked to list what they thought were important ergonomic features of the ECR. This covered everything from ambient environment, to adjustable chairs, to how they felt about the alarm system aid. The opinions were fairly unison on most subjects, especially those regarding the ambient environment.

4.2.1 Ambient environment

All groups pointed out the ambient environment aspects to be very important. This includes parameters such as climate (temperature, air movement etc.), noise, lighting, and vibrations. Temperature and noise levels were the most common feature mentioned. Having a functional air-condition creating a neither too hot nor cold environment was not described as a certainty by the gathered experience of the participants. This despite having an air-conditioned control room is the only recommendation found in the MSC Circular 834. Noise levels, usually mentioned in conjunction with vibrations, were reported as mixed between ships. Some descriptions of ECR's placed near high-speed engines or above propeller shafts, fuel booster pumps etc. witnessed of disturbing noise and vibration levels in the ECR. This was described as fatiguing and annoying. Henceforth, the ECR placement in the vessel was deemed as an important design parameter. Double doors to engine areas, which could trap both heat and noise, were proposed as an essential design to remove much of the noise when entering or leaving the engine room. All workgroups agreed that daylight armatures are preferred. Older fluorescent or halogen lamps with flickering or warm lights were spoken about as fatiguing while the colder daylight made you feel more alert. Several attendees reported about lights actually being changed to newer LED's while they were onboard, all of them reported it as uplifting for the ECR environment. One participant also reported that on one ship he had worked on, the ECR had port holes letting daylight in. He stated that the daylight in conjunction with having the ability to actually look out onto your surrounding had a positive effect on him. Another lighting aspect mentioned was reflections in computer screens. The response about this was mixed, some were clearly more bothered by it than others, but all agreed that if the reflections could be avoided it would be the best. One participant described that if he were working alone in the ECR, he would turn off some of the light armatures just to get rid of reflections in his work panels.

4.2.2 Physical ergonomics

It was discussed that ship type and size could set different requirements for ergonomics. The workday and time spent in ECR at a passenger ship with several standby's a day compared to smaller cargo vessels, or ocean-going ones, with periodically unmanned ECR's differ and therefore it was argued that good ergonomics may be more important on the passenger ships. Overall, this could somewhat be observed during the discussions where smaller cargo ships were sometimes pointed out as having worse ECR's in terms of basic ergonomics, and coastal ferries having more *"decent"* ones.

4.2.2.1 Layout and system overview

Open control room design was considered favorable. Tight space and inability for overview was two of the main flaws of several ECR's mentioned. ECR layouts where working desks were facing away from or far away from the control panels was described as bad for workflow and ability to oversee the systems at all times. If the operator were to sit at his or her desk performing office work, and an alarm goes off, one would have to drop everything, turn around or walk over towards the control panel to acknowledge the alarm, then go back to the desk and continue working. All argued this as annoying and hampering on your ability to get a good workflow going while performing the high amount of office work required. Good examples were provided of ECR's where the work desks were either facing the control panel or had the control systems integrated into the office space (e.g. by an extra control system screen next to your office computer screen where the operator could check on system in a quick and easy manner). The control panels themselves are described as big and bulky steel terminals that served its purpose back when most systems were analogue and in need of good space for cables and components, but their use today was questioned. They were described as taking up unnecessary space in the already cramped ECR. Participants also mentioned ECR's with big pillars or solid objects in tight areas or at the control panels, this was seen as poor design choices and a clear issue, both for normal operation but especially in emergencies or upped manning.

Large, modular screens placed at the right angles and position, where the operator can put up whatever information he or she wants was appreciated by the workgroups. This was mentioned as essential for the ability to obtain situation awareness about the current state of the ship or plant. Lack of these screens or older analogue ECR systems presented issues with either having to search through different computer screens or the operator having to move around and check a lot of system statuses on the permanent analogue panels. Having the ability of creating macros with toggleable screens or keeping situational ones depending on the current operational mode or work in progress was considered valuable in unity amongst the groups. A concept called *"situation board"* was described from the cruise ships. This was large touchscreens placed in key areas such as the ECR and bridge which was updated hourly and contained easy to grasp information about what systems was running and what kind of work was currently being undertaken all around the ship. These screens helped the person entering the ECR for his or her shift, or any additional called in personal, getting quick situation overview of the ship.

"[authors own translation] On a ship I worked on, if I was sitting at my panel and I wanted an overview of the essentials, I had to back off and twist my neck a lot to see the screen. So, the possibility to get a good overview of system status is there but it is far from ergonomic. The panels are placed almost 90 degrees from me and too close."

"[authors own translation] What I like about computer screens is that I can put up exactly what I want on them, and I can create macros with different operational data up depending on situation. At fire alarms as an example, the camera nearest to the area where a fire detector has gone off will zoom in onto the area, very good for me [for situation awareness]. What I miss from old control rooms is that there you have that oil meter or similar equipment, always there, always visible. New computer systems are not

always as clear even if you have a nice panel up on your screen. An analogue gauge differs from the digital ones. Here the development of digital data presentation of static information that I need has not quite reached the goal."

4.2.2.2 Office ergonomics

Office ergonomics of the ECR was pointed out as one of the main culprits hampering the work environment. The standards differ from ship to ship. For example, office desks, chairs, and computer screens could be of any quality and possibly even lack adjustability entirely. The office spaces have mostly some sort of middle height not really suitable for either sitting or standing, resulting in the operator being forced into standing in uncomfortable, leaning positions to operate the panels; the ability to choose to work either sitting or standing depending on preference was lacking in all cases described. There are usually no means of shielding the computer screens off from light reflections either. In the cases were workshop attendants described having to perform office work at the control terminals, the terminals surfaces are generally not flat, but instead being slanted and sometimes made of a slippery metallic finish, making papers, pens, calculators or other objects easily slide off the bench onto the floor. U-shaped desks were lifted as good tables where you had good space to work and put out papers, logbooks etc. Testimonials of problems with sitting on chairs with wheels onboard rolling ships were mentioned. Only one example of an ECR with stationary, higher quality chairs similar to those found on the bridge was mentioned. Having good shelf and drawer space allowing for easy to access and organization of hardbacks, instruction books, drawings etc. and proper tables to spread out large technical drawings was sought after.

"[authors own translation] Important aspects are that you have a position where you can get a good overview of what is happening. That you have a good working position and posture so that you can easily operate and change your overview whilst still being able to sit down and write logs and other paperwork that you are required to do today. If I want to sit down and work, I should be able to. If I want to stand up and work, I should also be able to. Adjustable height desks and the ability to adjust the angle of the screens in the panels depending if you are standing or sitting by them are needed."

4.2.3 Cognitive ergonomics

The cognitive aspects of the ECR were continuously discussed, including argumentation about older analogue ECR designs versus newer computerized ones, how alarm systems aid the operators work, and how traffic and other disturbances affect the work environment.

4.2.3.1 Design

Several points were made about the design and appearance of modernized computer panels. This of course varies between system developers, yet still there was no clear consensus about if modern mimic designs on computer screens are better than old analogue panels in terms of data presentation. Some argued that it is generally easier to get overview of what systems or tanks etc. that are in use on the analogue panels where most often a green light indicated that something is in use, while a red or turned off light means it is not. Identification by colors and patterns was described as very quick ways of getting situation awareness. These lights are generally also easily seen from most places. The experience of computer screen mimics was that sometimes the screens might have shown a lot of useful information but the mimic icons, color contrast, or viewing angles may be insufficient for quick identification. Color coding in particular was highlighted as a helpful tool when designing mimics (both on analogue panels as well as computer mimics) to let the operator quick and easy follow pipes or system drawings to find the correct valves or pumps to operate. Examples of both old and new ECR's with good color coding were mentioned.

> *"[authors own translation] There is something tactile with analogue gauges that the digital versions do not offer in the same way. But the positive thing with digital panels is that you can hide what is not interesting for the moment, while analogue panels are always there."*

Grouping of related systems on the control panel helps the workflow, the participants mentioned examples where e.g. not all controls for the auxiliary engines were grouped up in one place and that was considered bad for general control, especially if quick actions were needed. Relevant pump controls were placed several meters away as an example. The workshops described a common view of the design and layout of controls on the panels to be far from standardized. Some control panels seemed to be thrown together rather than being designed with some sort of systematic thought. All attendees described experiences with ECR panels having been patched up with new screens or controller boxes, with mixed reviews. While they agreed that more screens is generally better (because of better ability for more data presentation, and less congestion if you have to keep one or some panel(s) occupied with dedicated pages such as the alarm list), there was also a common voice that several of these patches were unnecessary and clumsy after-installations, sometimes at bad angles or locations where space permitted.

During research question III while discussing the cargo ship ECR, attention was drawn towards the roof mounted ECDIS (Electronic Chart Display and Information System) screen directly under a fluorescent armature. It was discussed that this made the screen hard to read which is a concrete example of a poor after-installation. A more thoughtful design from the start could have eliminated the need for the extra panel in the sometimes already fully packed control panel. Radar, ECDIS, and surveillance camera panels showing where the ship is and what it is currently doing was praised. Getting information about the world around you made the participants feel better and less disconnected from the real world inside the engine rooms. Port holes allowing for sunlight in and the ECR personnel to look out was also praised.

4.2.3.2 Alarm systems

The alarm systems were talked about as generally poorly designed in terms of aiding the operators. Having one type of alarm category and light & sound signal does makes every alarm seem equally important to address in a quick manner. This was described as troublesome if the engineer is working a lot inside the engine room. For every small and sometimes insignificant alarms the engineer would have to instantly drop everything and rush back to the ECR to just to silence the alarm, and then get back to work. This made it sometimes impossible to perform effective work inside the engine room. Similar issues were pointed out if you do get a major failure, there's generally nothing indicating that more than one engine alarm has gone off simultaneously until either you get to see the alarm list, or you notice something breaking or shutting down. To aid the operator, it was suggested that having two or maybe three alarm categories, normal, high priority, and a signal for multiple alarms going off, could be beneficial. The alarm list panel could also support color coding of alarms to highlight related systems or identify priority alarms. Participants described scenarios where one small issue snowballed and triggers an armada of other alarms. When the alarm list quickly fills up it can be hard and stressful for the operator to get an overwhelming wall of text of the same formatting, as todays alarm lists mostly are described as. Furthermore, regarding the light and sound alarm signals in the ECR, there was mixed opinions. Some argued that it is good that there is both, in the case of one system failing (one participant described an experience where a breaker had tripped for the light signal in the ECR, they noticed it because the sound signal went off, without any flashes). Others argued that using only one of the two are good enough. A common identifier was that the sound signal was often unnecessarily loud, which would act as a stress moment in the ECR, especially if multiple alarms are going off in sequence.

Having split up alarm systems was described as a bad thing. Experiences of the main engine or boilers having a panel of their own, resulting in alarms having to be silenced and acknowledged on both the component panel as well as the central alarm system was mentioned. The common opinion was that if you silence an alarm in one place, it shall be silenced everywhere. Also, experiences with terminals giving the ability to check the alarm panel and acknowledge alarms while inside the engine room was reflected upon as good experiences. For engineers who spend much time in the engine room this helps them with their workflow when they can identify when they actually have to go all the way back to the ECR or not.

" [authors own translation] There was once when the shaft in the shaft generator cracked during the night, then you had a situation when you came down to the engine area and saw everything shutting down. Then you had to go out and find out a lot by yourself because the alarm system hadn't really helped you. Everything went to auto-shut down but no general alarm or anything had gone off, only the regular engine alarm. If you hadn't noticed that things started bouncing and banging, you could feel it up in your cabin, you wouldn't have realized it to be so serious. So, there was no indication of multiple alarms going off since the alarm system doesn't react any different. Had there been another alarm signal or something, I think it

would have us helped in this situation. We could have had use of all hands going down from the start there because of the seriousness of the failure."

4.2.3.3 Traffic through ECR and other disturbances

Traffic through ECR was described by all groups as a nuisance for the crew working inside the ECR. Both the opening of doors towards loud areas as well as the persons themselves, could act as disturbance for an operator performing cognitive-heavy work. If the ECR is the only mean of transportation between two engine areas, it was lifted as important that control panels or office stations are placed next to the ECR doors to eliminate eventual collisions and minimize disturbance. Having the only toilet inside the ECR, or the control room acting as transport between different engine areas also contributed to disturbing traffic according to the workshops. The toilet inside ECR was not wanted both because of the traffic factor as well as the discomfort in case of bad smells etc. To minimize disturbances, having as few personal offices as possible inside the ECR was proposed by all groups. Having the chief and electric engineer offices inside the ECR in particular was questioned. Communication with other crew or parts of the ship, in an easy and effective manner was described as important but the means for it as a mixed experience. Threaded phone stations were reported sometimes as being placed in locations where you could not reach essential controls or stations. Wireless phones or room-wide talk-back systems were mentioned as good systems for effective communications while still being able to work efficiently.

4.3 Research question III - Given existing control room designs, how would its operators redesign them for optimal ergonomics and function?

Workshop one was presented the general arrangement of the ECR of a small tanker of ~110 m LOA (length over all). Workshop two and three in addition to the tanker got presented the ECR of a ~ 200 m LOA cargo ship.

4.3.1 Tanker ECR

The general arrangement of the tanker ECR is presented in figure 4.1. The general thought of this ECR was that it seemed to serve its purpose considering the relatively small ship size. The floorplan was deemed as ok. Having the coffee and toilet area inside the ECR was a main discussion dividing the groups opinions, some liked it, and some thought it would be a disturbing factor inside such a small ECR.

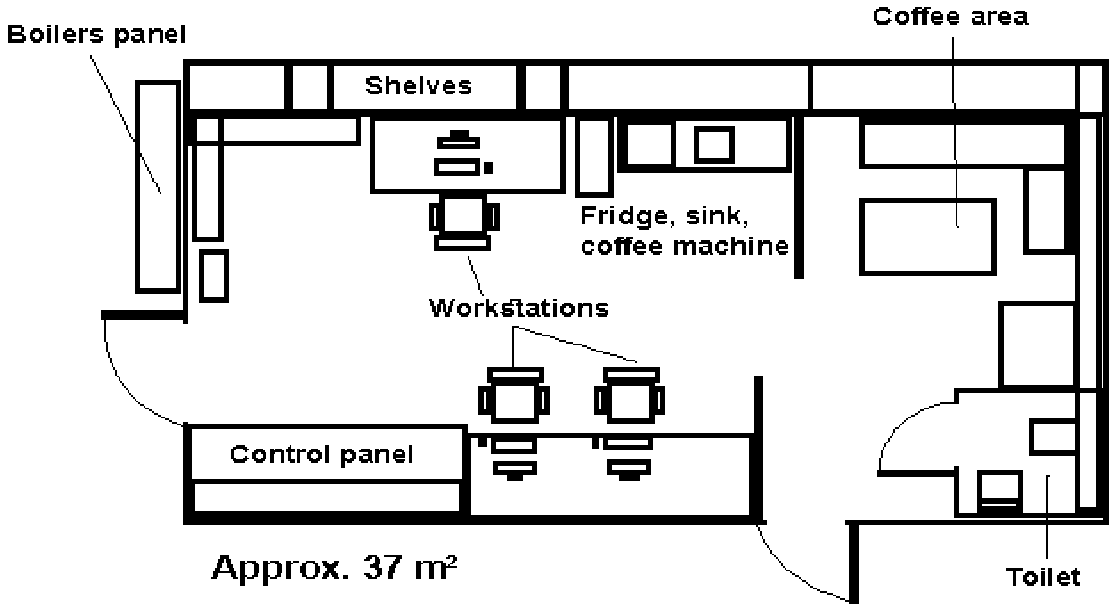

Figure 4.1 Tanker ECR presented to all workgroups.

4.3.1.1 Commonly identified issues

- The main issue identified by the groups was the pathway through the two doors in to the ECR, where one door is placed right next to the control panel. Clear issues with collisions or annoying traffic around the control panel and workstations was highlighted. It was also proposed that it could be more noise near the door.
- The control panel is of a straight panel type placed in a corner, the ability of getting good overview of the panel from all relevant positions of the ECR was questioned. Since there are walls shielding off the coffee area, the ability to see the control panel from there was pointed out as less optimal.
- The office desks were pointed out as not placed in a way that gives good overview of the control panel. To have three workstations in an ECR of this size was questioned, one or two was suggested as enough to give the operator(s) more space.
- Opinions were split about having the coffee area inside such a small ECR, but all agreed that the Toilet should be separated out from the ECR.

4.3.1.2 Proposed changes

Figure 4.2 and 4.3 shows new suggested arrangements based on the following changes:

- Reduce number of workstations to two.
- Remove the partial wall to the coffee area.
- Swap position of door with boiler panel to create a less disturbing pathway through ECR and possibly enabling an L-shaped control panel (as in Figure 4.2).
- Possibly swap position of the coffee area and the control panel and make the panel L-shaped in the corner (as in Figure 4.3).

- Separate the toilet from the ECR by extending the wall separating the coffee area and the toilet and place the entrance door there instead.

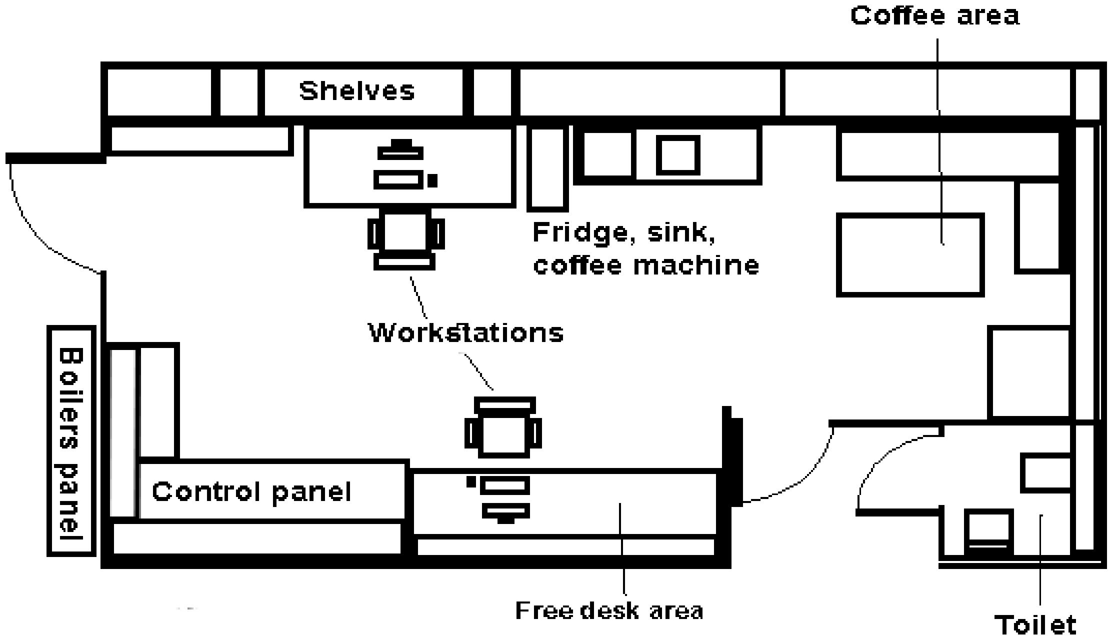

Figure 4.2 A redrawn arrangement of the tanker ECR based on feedback from the workshops.

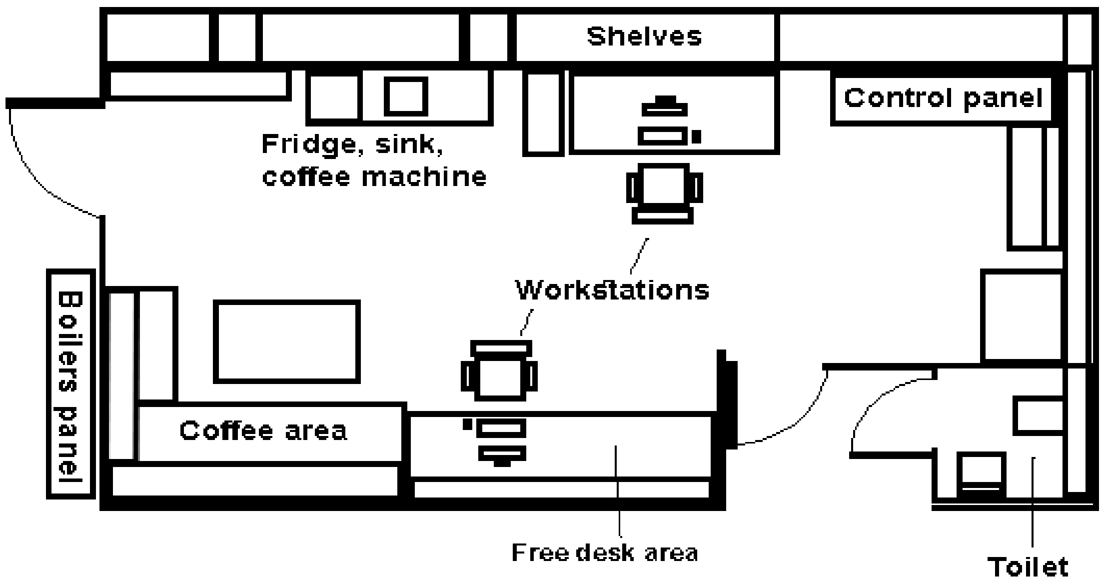

Figure 4.3 An alternative redrawn arrangement of the tanker ECR based on feedback from the workshops.

4.3.2 Cargo ship ECR

The general arrangement for the cargo ship ECR is presented in figure 4.4. Multiple participants had experience working in this type of control room. The overall impression of this ECR was positive. Elongated ECR's were spoken of as positive as they can house a coffee area without making it cramped up with the office and operational area. The windows facing the engine room was appreciated as direct overview of the main engine could be kept while standing at the control panel. The office space (albeit facing away from the control panel) was described as good by participants whom themselves had worked in control rooms like this one.

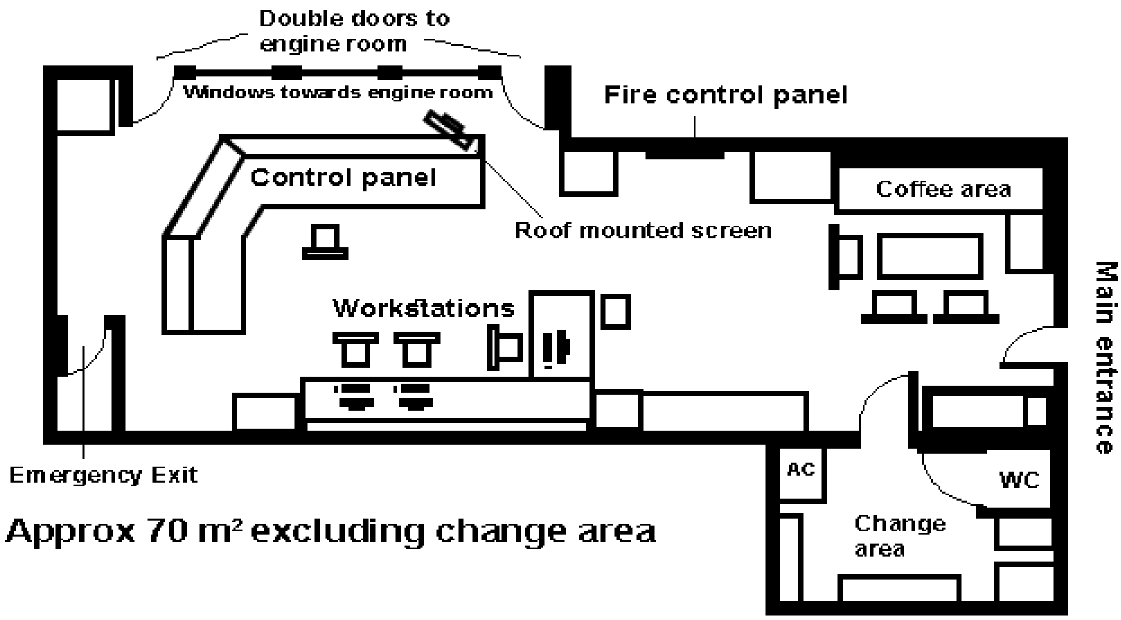

Figure 4.4 Cargo ship ECR presented to workshop two and three.

4.3.2.1 Commonly identified issues

- Participants who had worked with this type of control room described the control panel as a little inflexible to work with, having only two control system screens and a wide mixture of old and new gauges and controls. The control panel was also pictured as big and bulky with no means of ergonomic adaptation. System overview was described as bad, with no larger panels showing operational data. If the operator wanted to know any data, he or she would have to dive down into the control system screens.
- The roof mounted screen was pointed out as mounted directly under a fluorescent light armature, making it hard to read in addition to being mounted at a bad view angle.
- Although the toilet is separated off into the changing area, it was still pointed out that this is the only toilet in the engine area and could only be accessed by going through the ECR. Either adding an extra one in the workshop or engine area or moving the existing one out into the stairway to reduce traffic was suggested.

4.3.2.2 Proposed changes

Figure 4.5 show a suggested arrangement based on the following changes:

- Move the control panel down towards the windows to create more space between the workstations and the panel, potentially enabling the workstations to be turned towards the control panel.
- Remove some of the old analogue controls and install additional computer screens instead.
- Remove the roof mounted screen and integrate this into the control panel.
- Modernize the control panel with a less bulky terminal.

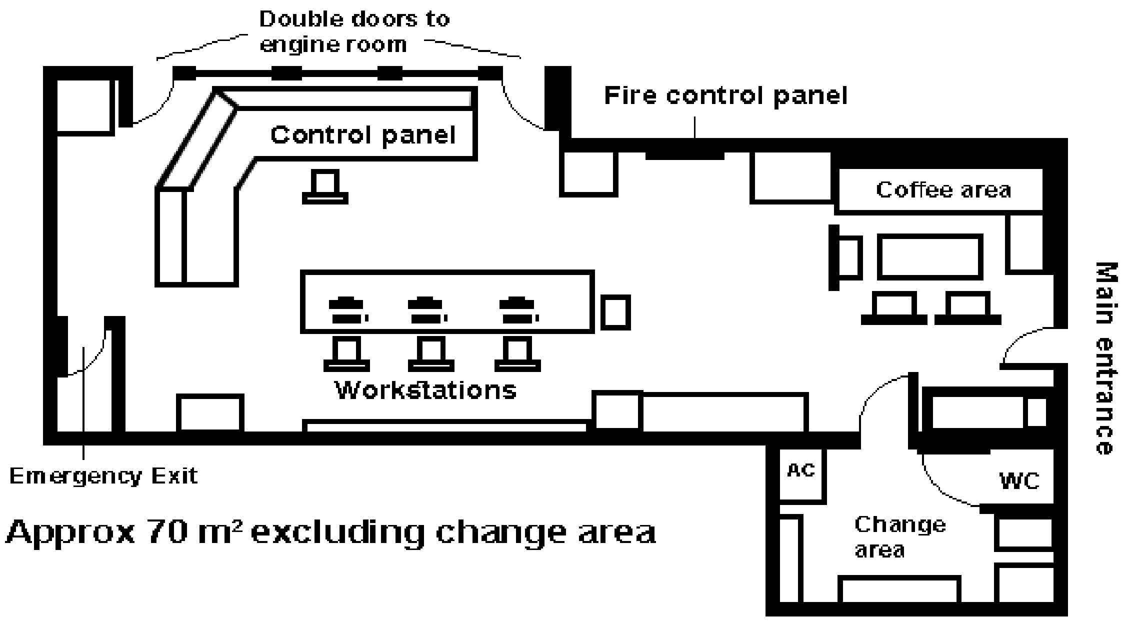

Figure 4.5 A redrawn arrangement of the cargo ship ECR based on feedback from the workshops.

5 Discussion

The results from this thesis support the idea from previous research that the design of the engine control room is not prioritized nor standardized (Ivergård & Hunt, 2009). According to the workshop participants who compared older ships, around 40 years old, to the newer ones, approximately 3 years old, not much seems to have happened regarding ergonomic standards. They still have the big, bulky, and non-adjustable steel control panels despite research indicating the importance of ergonomics. Since there are only a few guidelines from the IMO, the general modernization process of the ECR has proven slow and only based on individual branch initiatives such as those made by actors of the cruising industry mentioned in this thesis. The improvements according to these results, however, tend to address security and safety aspects rather than ergonomic issues. The workshop attendees suggested that engine personnel seldom complain about ergonomic or work environmental issues which may have an impact on how these matters are handled. This, in addition to the lack of recommendations or mandatory requirements for compliance, generate speculation that the interest from companies to invest financial resources into addressing the issues, are of low priority.

During the workshops each of the eleven attendants were asked to individually grade the general ECR of today as a workplace on a scale of 1 to 5, where 1 means ECR is a very bad workplace, and 5 means that the ECR is very good. With a total of 11 votes, the result was four 2's and seven 3's averaging 2,64 out of 5. It was a common opinion that that the ECR is mostly "fair" to work in, but much further behind a landside office in terms of ergonomics. This question was asked to get an easy and general view from all attendees about the overall experience of the ECR in addition to the more specific discussions. This general view matched the more detailed discussions of the ECR as functional for the most basic tasks, but not really for the all the extra things you need to do such as documentation.

5.1 Research question I - How does the engine crew perceive the work environment in the engine control room?

The stagnate evolution of ECR design is unfortunate when the duties of the ECR operators have changed towards a different, more administrative style of work (Lundh & Rydstedt, 2016). This has created a mismatch of workplace ergonomics versus expected duties. This is supported by the findings of Grundevik, Lundh, & Wagner (2009) stating that the design of the modern ECR does not support the work of the operator, when the administrative duties have increased. Workshop attendees agreed upon a description of a general workday of the ECR operator today as consisting of 50 % office work, while the standards of the office workstations were described as generally better in older ECR's than newer ones where the operator may be expected to perform office work at the control terminals. The reason older ECR's may have offered more optimal office spaces may originate from the fact that all office work and documentation was previously performed in paper form, while today these duties are mostly (but not exclusively) computer-based, which in modern style ECR's may be integrated in the control panels. Today however, when the equipment used in the ECR has become more computerized during the last decades, *"the growing gap between technological advancement and the continuously traditional design may also pose a threat to the safety of the ship and crew's performance"* (Mallam & Lundh, 2013). This statement is backed by this thesis' results where an attendant described after a six-hour duty shift having pain in shoulders and neck and a stiff body, indicating less than optimal working conditions in the ECR, putting the alertness of the operator at risk, which in turn can jeopardize the performance and safety of the ship.

In contrast, navigation bridge layout and consoles tend to be more similar between different ships. This is likely because bridge layouts and designs have concrete guidelines such as the MSC Circular 982 by IMO, and the *"Guidance Notes on Ergonomic Design of Navigation Bridges"* by the classification society ABS (2003). This ensures a good working environment for the deck officers as they have ergonomically adapted workstations, which may aid them in becoming familiarized with a new ship faster and may also help training them to a generally better proficiency since they often work with similar panels in similar environments. The design and functionality of the bridge is also incorporated in SOLAS V/15 which is then a mandatory requirement (IMO, 2002). Workshop attendants argued that more comprehensive guidelines could be equally beneficial for the engine department if applied to the ECR as well. Instead of having no standardized layouts or designs making every ECR unique in appearance, a thorough, complete, and whole ECR design was asked for by the groups, and not a patchwork of different solutions described sometimes as added first after a long time with issues.

5.2 Research question II - What ergonomic consideration need to be taken into account to create a good work environment?

The office ergonomics in the ECR, or rather the lack thereof, was discussed in the workshops. The work environment of the ECR does not have ergonomically adapted workstations, and the preference for a sit-stand station was discussed amongst participants; which none had ever experienced in an ECR. The main issue with the control terminals is that they are not adapted for sitting nor standing, which made this topic something that participants deemed as a major issue when it comes to the ergonomics in the control room. The research performed by Robertson, Ciriello, & Garabet, showed that a sit-stand workstation along with ergonomic training, prevented injuries and led to increased performance in work tasks (2013). The author believe implementation of proper ergonomic workstations in the ECR would probably not be a major economic issue, but as mentioned in the workshops, it is firmly believed that the ECR as a workplace is not prioritized in the design and construction of the ship, which is an issue for the safety and wellbeing of the workers in the engine department.

Possible solutions to these ergonomic issues would be to adhere to the ABS' recommendations in *"The application of ergonomics to marine systems"*. In the guidance notes that have been created by this classification organization, a vast amount of suggestions on how to implement ergonomics in the marine sector are suggested. Guidance is provided on design and layout regarding ergonomics. It contains information on recommended design of human to system interface with displays, alarms, workstation height levels, workspace access and the arrangement of the workplace, and more. The guidance notes contain information on computer-based workstation ergonomics, and particularly on sit-stand workstation for those in a control room. Adhering to the guidance notes could substantially improve the ergonomic- and overall work situation of the personnel in the engine department. However, the ABS guidance notes are not mandatory. The authors of this paper believe that if guidelines such as these were mandatory, there would be a significant improvement in the design of a vessel and its ECR, thereby improving the work environment. As previous research has shown, ergonomically adapted workstations and pleasant work environments have positive impact on both injury reduction and elevated performance in work tasks (Chim, 2014). Adapting the ECR to the personnel would contribute to a safer, more productive, and overall better work environment in the engine department.

While the ambient environment was widely regarded by the workshops as one of the most important aspects, this part is, as previously proven by the INTERTANKO report, disregarded by legislations. MSC Circular 834 only recommends the ECR to be air-conditioned for the sake of good ambient temperature for switchboards and electronics. The scope of the MSC Circular 834 reads that *"These guidelines are intended to improve engine room safety and efficiency and overall vessel safety…"* (IMO, 2002), yet still it doesn't cover anything more in the ECR with regards to the operator well-being. The results of this work clearly state that these recommendations are non-comprehensible and needs to be expanded to include the other aspects of the ambient environment such as noise, vibrations, or lighting. The importance of these aspects to create a good and safe workplace with a healthy and productive work force has been well described by previous research (Chim, 2014; Robertson, Ciriello, & Garabet, 2013; Ergoweb, 2010), and the material is already available, as in the ABS guidelines (2013), but they need to be implemented and made mandatory for the ECR.

Situation awareness was frequently mentioned amongst the workshop participants, most often related to the ability of quickly getting a good overview of the ship's status by either one operator or multiple simultaneously. Previous research has indicated that having a modern, computer screen-based control room increased the overall team situation awareness of the operators compared to that of when using a traditional styled control room (Seung, Ar, Jinkyun, Hyun, & Poong, 2016). However, when the workshop groups discussed advantages and disadvantages of traditional versus modern, computerized ECR designs, there were mixed experiences of whether the modern computerized design really did provide means for better situation awareness compared to traditional style with older analogue panels. The greater picture seems to be that the technology is considered to be available, but often poorly executed. Modern computerized ECR's must be flexible in function and have large, well placed screens to provide a good overview comparable to that of the older analogous panels. Previous research has pointed out the benefits of analogous equipment providing immediate information accessible for everyone in the ECR (Lundh, 2010), and with current technology there should be better ways to mimic these panels with screens. The importance of not having a too complex computer menu structure that does not force operators to dive down into multiple mimic, drop-down menu, or data screens to obtain the necessary data was described as key, as has been proven by Wagner (et al., 2008) where several of the investigated control system software's used a menu hierarchy unnecessarily complex and with ill-suited input devices for ship conditions with vibrations and rolling.

The function of the onboard alarm systems in the ECR were discussed in the workshops. Participants had different opinions regarding alarms, but the conclusion amongst the majority was that the alarm system generally was not helpful for the operator if hectic situations occur. This is because the same alarm signal is given, regardless of whether it is an important alarm of high priority or a low priority alarm. Participants suggested that alarm categories with different distinguishable signals, possibly two or three, would be beneficial. One for normal, another for high priority, and potentially a third category for multiple alarms going off at the same time. Previous research has shown similar results, where engineers have apprehended the alarm systems as not optimized and incomprehensive to use (Lundh, 2010) and Thunberg & Osvalder (2009) states that alarm prioritization and abilities to inhibit unimportant alarms can benefit the operator in his or her work. In the workshop, the audio alarm signals were also deemed often to be unnecessarily loud, causing stress and irritation. This could potentially also make the operator better aware of and prepared for the situation which is to be handled. Also, Wagner identified all these issues with the alarm systems onboard several ships in his field studies, either the alarm signal was too loud or not distinguishable enough from other ambient noises or signals in the ECR or engine room. He also concluded that the alarm systems needed to better distinguish the seriousness of the alarm, and that slave alarm panels in the engine room would help the engineer working in the engine room (Wagner et la., 2008). A suggestion by authors of this thesis would be to create an additional set of alarm signals, of a different frequency or volume (for audio alerts) and a different pulse frequency or color (light alerts), to get a better estimation of whether the alarm sound is something which requires immediate action or not; clear separation in sound or light signal between a high priority and a low priority alarm, similar to the annunciator panels found in aircrafts.

5.3 Research question III - Given existing control room designs, how would its operators redesign them for optimal ergonomics and function?

The results indicate that the participants would like to see improvements to the design and layout of existing ECRs. This part of the workshop allowed the participants to use their own imagination and think outside the box about how they could optimize their work environment, and the suggestions generated by the participants can be found in Figures 4.2, 4.3, and 4.5. The suggestions provided by the workshop attendants to change the given ECR designs mainly focused on opening it up for more a spacious design, modernizing equipment, reducing traffic, and increasing system overview. The participants' active choices of improvements can be viewed as further strengthening the reasoning of research question I and II, as their choices align with the theoretical discussions where e.g. an easy-to-overview control panel with modern work terminals was considered important. The tanker control panel was suggested to change from a straight-line type to a banana/L-shape for better overview and the half wall between the coffee and work area to be removed to reduce blind spots. Regarding the cargo ship, in addition to wanting a modernized, adjustable control panel with more computer screens, the aim of moving the panel was to create a larger square of floor space between the office terminals and the control panel. Similar results can be found in the field studies by Wagner et al. (2008), where e.g. ECR and console layouts from different ships are practically compared and investigated with regards to overview (in terms of general layout and potential blind spots), sit/stand ergonomics, movement patterns of ECR crew during operation, and reasonable grouping and spacing of equipment. In particular, square shaped ECR's provided the best space optimization and overview, with banana-shaped control panels pointed out as the best choice for ergonomics and overview.

5.4 Method Discussion

In qualitative studies it is difficult to apply, and by some researchers argued inappropriate, to use reliability and validity for evaluating the quality of the research (Stenbacka, 2001; Leung, 2015). Alternative terminology is suggested to describe the quality and consistency of the work. Stenbacka (2001) use the opportunity for the informant to speak freely and express their knowledge about the topic as "validity". Reliability is measured against a thorough description of the process, data gathering and analysis (Sykes, 1991).

The chosen methodology was focus group workshops with a qualitative approach. The participants were marine engineers and marine engineer students. Thematic analysis was used to interpret the data collected. This methodology was deemed appropriate for the cause, which was to get a broad view from participants of the workshops, with a limited number of available participants and a narrow time frame to perform the research. The research conducted on thematic analysis by Braun & Clarke, (2006) provides advantages and disadvantages of thematic analysis. Advantages of thematic analysis includes flexibility, easily comprehendible method, successfully summarizing large quantities of data, and several more. The possibly most important advantage for this thesis is that it is a useful method for producing a qualitative analysis meant for policy development. Disadvantages of the thematic analysis is that the researcher, with the wide range of information gathered through the data collection, may experience difficulties in deciding what data to focus on, which can cause inconsistency in the themes. Neither does thematic analysis have kudo as an analytic method compared to well renowned methods such as grounded theory (Braun & Clarke, 2006).

Qualitative research was deemed the appropriate method as this allows for the researcher to form his or her own opinion regarding the topic, which improves the chances of achieving meaningful results. A wide range of information can be presented with the authors own interpreted opinion on what is deemed most relevant for the specific study (Harwell, 2014), which suited this thesis. A quantitative approach, presenting gathered or generated values, would not adequately address the research questions discussed within this thesis.

A potentially limiting aspect of this research was that out the 11 participants on the workshops, 10 were students. The students have limited experience in the field of marine engineering and working in an ECR, however, their credibility as participants is deemed as strong and very valuable, as the participants were selectively recruited. The demographics of the students who participated in the workshops were rather similar. All participants were male, which potentially limited the study from achieving a wider aspect of opinions on the matters discussed in the workshops. A larger number of actively working marine engineers, with more experience, could also provide further valuable input to this thesis. It would have been desired to have a better mix of demographics, female participants, and a few more actively working marine engineers. However, the positive aspect of having marine engineering students as participants of the study is that they have relatively recent experience of several different control rooms from their internships which are included in the education, all in a limited amount of time. This potentially made it easier for them to compare different control rooms as they were not limited by having worked in the same ECR for a very long time, which could form their opinion to only have one specific ECR in mind when performing the workshops.

6 Conclusions

The results of the gap pinpointed by the INTERTANKO report regarding the fact that the ECR falls outside of existing guidelines and regulations surrounding the engine areas, becomes clear when hearing the workshop attendants' varying experiences from ECR's of today. The results from this study is of the same conclusion as the INTERTANKO report. The environment of the ECR should be in equivalence to that of a normal office environment, in the ways this is possibly applicable. The INTERTANKO report stated that consideration should be taken to physical ergonomics, lighting, noise, vibration, ventilation, and temperature of the ECR. The authors of this paper agree with this, and adaptation of the ECR is deemed necessary to create an improved work environment. The authors believe both ambient environment and office ergonomics need to be considered when constructing and designing an ECR. Since IMO is the highest governing body of international shipping, to get the market to actively work towards better designing the modern ECR's, the MSC Circular 834 must be updated with broader sections including rules for ergonomics such as appropriate temperatures, lighting and noise levels, vibration, ventilation and office ergonomics for the ECR.

Previous research indicating that the ECR is mismatched against todays expected work duties are fully supported by the results of research question I – *"How does the engine crew perceive the work environment in the engine control room?"*, in this report. The workshop attendants described a general workday in the ECR as at least 50 % office work while the ECR tend to lack good office spaces. None or very few general developments towards better office environment could be endorsed by the participants. Office ergonomics, considered to be of high relevance to the modern type of ECR operator work, seems to have an issue with large variations of quality based on the workshop participants experiences onboard, which further indicates a need for standardization. The means for creating a better working environment, where physical ergonomics factors such as awkward posture, work style, and design are not neglected is a necessity. For example, the operator should have adjustable workstations with good overview of the controls, or a workstation which is adapted to both operative- and administrative work.

The ambient environment is pointed out as important, yet not always of acceptable standards. Less than optimal lighting and uncomfortable temperatures for example are still being experienced in ECR's of today. There are small signs of improvements though, as daylight LED's are to an extent being installed onboard ships. But more need to be done in stipulating concrete rules for all aspects of the ambient environment, as can be found in land-based safety at work-acts or the ABS' guidelines.

Answers from research question III, "*Given existing control room designs, how would its operators redesign them for optimal ergonomics and function?"*, seems to further strengthen the workgroups discussions in research question I and II. The discussions based on the attendees' own experiences were practically applied to given designs and their suggestions of improvements were in line with both earlier discussions in the workshops, as well as previous research.

It is the authors' view that the MSC Circular 834 should be just as detailed about the ECR as the MSC Circular 982 is regarding the navigational bridge, and that it should be made mandatory instead of guiding. The document should cover the ambient environment, office ergonomics, and design & layout standardizations in order to provide a safer and better working environment for the ECR crew.

7 Future work

More work towards making ergonomic standards mandatory is needed. The material is already available to a large extent through classification society guidelines, ISO standards etc. However, since these documents are not applicable to the ER and ECR, and they are not mandatory, the ECR has not been prioritized in terms of ergonomics and human performance. It could be argued that the ECR should be considered an office space rather than an engine space, with office ergonomics properly applied.

8 Acknowledgments

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9 References

American Bureau of Shipping (ABS) (2013). The Application of Ergonomics to Marine Systems. Retrieved on May 6, 2020 from https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/86_applicationsofergonomicstomarinesystems/ergo-gn_e-aug18.pdf. Houston, TX 77060, USA.

American Bureau of Shipping (ABS). (2003). Guidance Notes on Ergonomic Design of Navigation Bridges. Retrieved on May 6, 2020 from https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/conventional_ocean_service/119_ergonomicdesignofnavbridges/bridge-ergo-gn-aug18.pdf. Houston, TX 77060, USA.

Braun. V., Clarke. V. (2006). Using thematic analysis in psychology, Qualitative Research in Psychology, 3:2, pages 77-101. Retrieved on April 28, 2020 from https://doi.org/10.1191/1478088706qp063oa.

Chim, Justine M.Y. (2014). The FITS model office ergonomics program: A model for best practice. Vol. 48 Issue 4, p495-501. 7p. 1 Diagram. Database: Business Source Premier. Retrieved on April 22, 2020 from https://doi.org/10.3233/WOR-131806.

Det Norske Veritas, (DNV GL). *RULES FOR CLASSIFICATION* Part 6 Additional class notations Chapter 8 Living and working conditions. Retrieved on March 9, 2020 from https://rules.dnvgl.com/docs/pdf/DNVGL/RU-SHIP/2015-10/DNVGL-RU-SHIP-Pt6Ch8.pdf.

Ergoweb. (2001). Budnick, P., Michael R. What is cognitive ergonomics*?* Retrieved on April 26, 2020 from https://ergoweb.com/what-is-cognitive-ergonomics/.

Ergoweb. (2010). Ergonomics Concepts. Retrieved on April 26, 2020 from https://ergoweb.com/ergonomics-concepts/.

Grundevik, P., Lundh, M., & Wagner, E. (2009). Engine control room - Human factors. Chalmers University of Technology, Gothenburg, Sweden.

Harwell, M.R. (2014). Research Design in Qualitative/ Quantitative/Mixed Methods. In: The SAGE Handbook for Research in Education: Pursuing Ideas as the Keystone of Exemplary Inquiry. University of Minnesota. Retrieved April 28, 2020 from https://dx.doi.org/10.4135/9781483351377. Pages 147-164.

Heatherington, C., Flin, R., & Mearns, K. (2006). Safety in Shipping: The Human Element. *Journal of Safety Research*, 37. Pages 401-411.

International Maritime Organization (IMO). (1998). MSC Circular 834 GUIDELINES FOR ENGINE-ROOM LAYOUT, DESIGN AND ARRANGEMENT. Fetched on January 28 from http://www.imo.org/blast/blastDataHelper.asp?data_id=8819.

International Maritime Organization (IMO). (2000). MSC Circular 982 GUIDELINES ON ERGONOMIC CRITERIA FOR BRIDGE EQUIPMENT AND LAYOUT. Retrieved on February 2, 2020 from https://mcanet.mcga.gov.uk/public/c4/solas/solas_v/msc/msc982-ERG.pdf.

International Maritime Organization (IMO). (2002). SOLAS V Regulation 15 "Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures". Retrieved on February 4, 2020 from https://mcanet.mcga.gov.uk/public/c4/solas/solas_v/Regulations/regulation15.htm.

International Standard Organization (ISO). (1999). International Standard 11064-3 Ergonomic design of control centres - Part 3: Control room layout. Fetched on January 28, 2020 from https://www.sis.se/api/document/preview/616079/.

Ivergård, T., Hunt, B. (2009). Handbook of Control Room Design and Ergonomics (2nd Edition ed.): CRC Press.

Kaber, D.B., Endsley, M.R. (1998). Team situation awareness for process control safety and performance. *Proc. Safety Prog*., 17: 43-48. Retrieved May 4, 2020 from https://doi.org/10.1002/prs.680170110.

Leung, L. (2015) 'Validity, reliability, and generalizability in qualitative research', Journal of Family Medicine and Primary Care. Medknow, 4(3), p. 327. https://doi.org/10.4103/2249-4863.161306.

Liamputtong, P. (2015). Focus Group Methodology: Introduction and History. SAGE Publications Ltd. City: London. https://dx.doi.org/10.4135/9781473957657. Retrieved on April 28, 2020 from https://methods-sagepub-com.proxy.lib.chalmers.se/base/download/BookChapter/focus-group-methodology/n1.xml.

Lundh, M. (2010). A Life on the Ocean Wave - Exploring the interaction between the crew and their adaption to the development of the work situation on board Swedish merchant ships. Chalmers University of Technology, Gothenburg, Sweden.

Lundh, M., Aylward, K., Mackinnon, S., & Man, Y. (2017). On the adaption of the Guidelines for engine-room layout, design and arrangement. MSC/Circ.834; Report for INTERTANKO. (Report No. 2017:04). Chalmers University of Technology, Gothenburg, Sweden.

Lundh, M., Lützhöft, M., Rydstedt, L., & Dahlman, J. (2010). Working conditions in the engine department – A qualitative study among engine room personnel on board

Swedish merchant ships. Department of Shipping and Marine Technology, Chalmers University of Technology, Gothenburg, Sweden. https://doi.org/10.1016/j.apergo.2010.08.009. Retrieved on March 15, 2020, from https://www-sciencedirect-com.proxy.lib.chalmers.se/science/article/pii/S0003687010001237?via%3Dihub.

Lundh. M., Rydstedt. L.W. (2010). An Ocean of Stress? The relationship between psychosocial workload and mental strain among engine officers in the Swedish merchant fleet. Lillehammer University College (HiL), AHS, Unit of Psychology, Lillehammer, Norway & Chalmers Technical University, Department of Shipping and Marine Technology, Gothenburg, Sweden. Retrieved on March 23, 2020 from https://journals.viamedica.pl/international_maritime_health/article/view/26225/21019.

Lundh. M., Rydstedt. L.W. (2014). A static organization in a dynamic context – A qualitative study of changes in working conditions for Swedish engine officers. Department of Shipping and Marine Technology, Chalmers University of Technology, Gothenburg, Sweden. https://doi.org/10.1016/j.apergo.2016.01.006. Retrieved on March 22, 2020 from https://www.sciencedirect.com/science/article/abs/pii/S0003687016300060.

Mallam, S. C., Lundh, M. (2013). Ship Engine Control Room Design: Analysis of Current Human Factors & Ergonomics Regulations & Future Directions. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 57(1), 521–525. https://doi.org/10.1177/1541931213571112.

Man, Y., Lundh, M. & MacKinnon, S.N. Managing unruly technologies in the engine control room: from problem patching to an architectural thinking and standardization. *WMU J Marit Affairs* 17**,** 497–519 (2018). https://doi.org/10.1007/s13437-018-0159-y.

Olofsson, M. (1995). The Work Situation for Seamen on Merchant Ships in a Swedish Environment. Chalmers University of Technology, Gothenburg.

Osvalder, A.-L., Andersson, J., Bligård, L.-O., & Colmsjö, A. (2015). Ergonomic features of control room environments for improved operator comfort and support. Nordic Ergonomics Society 47th Annual Conference (NES 2015). Lillehammer, Norway. Retrieved on March 5, 2020 from https://www.researchgate.net/publication/283545169_Ergonomic_features_of_control_room_environments_for_improved_operator_comfort_and_support.

Riksdag (1977). Arbetsmiljölagen (AML) SFS 1977:1160 up to and including SFS: 2019:614. Retrieved on January 28, 2020 from https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/arbetsmiljolag-19771160_sfs-1977-1160.

Robertson, M.M., Ciriello, V.M., & Garabet, A.M. (2013). Office ergonomics training and a sit-stand workstation: Effects on musculoskeletal and visual symptoms and performance of office workers. *Applied Ergonomics* Volume 44, Issue 1, January 2013, Pages 73-85.

https://doi.org/10.1016/j.apergo.2012.05.001. Retrieved May 7th, 2020 from https://www.sciencedirect.com/science/article/abs/pii/S0003687012000622?via%3Dihub.

Seung W.L., Ar R.K., Jinkyun P., Hyun G.K., & Poong H.S. (2016). Measuring Situation Awareness of Operating Team in Different Main Control Room Environments of Nuclear Power Plants, *Nuclear Engineering and Technology*, Volume 48, Issue 1, 2016, Pages 153-163, ISSN 1738-5733, https://doi.org/10.1016/j.net.2015.09.008. Retrieved May 4, 2020 from http://www.sciencedirect.com/science/article/pii/S1738573315002247.

Simonsen, E., Osvlader, A.-L. (2015). Aspects of the nuclear power plant control room system contributing to safe operation. 6th International Conference on Applied Human Factors and ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015. http://doi.org/10.1016/j.promfg.2015.07.260.

Silverman, D. (2011). Interpreting qualitative data: A guide to the principles of qualitative research. London: SAGE.

Stenbacka, C. (2001) 'Qualitative research requires quality concepts of its own', *Management Decision*. MCB UP Ltd, 39(7), pp. 551–556. https://doi.org/10.1108/EUM0000000005801.

Swedish Transport Agency. (2019). Transportstyrelsens föreskrifter om arbetsmiljö på fartyg (TSFS 2019:56). Retrieved on January 28, 2020 from https://www.transportstyrelsen.se/TSFS/TSFS%202019_56.pdf.

Sykes, W. (1991) 'Taking stock: Issues from the Literature on Validity and Reliability in Qualitative Research', *Journal of Market Research*, 33(1), pp. 3–12. https://doi.org/10.1177/147078539103300101.

Thunberg, A., Osvalder, A. (2009). Good Practice Regarding Alarm System Design and Alarm Management Strategies for Complex Process Control Settings. VTT Symposium (Valtion Teknillinen Tutkimuskeskus). Pages 251-257. Retrieved on April 20, 2020 from https://www.researchgate.net/publication/289071713_Good_practice_regarding_alarm_system_design_and_alarm_management_strategies_for_complex_process_control_settings.

Wagner, E., Lundh, M., & Grundevik, P. (2008). Engine Control Rooms - Human Factors Field studies. MSI Design, Chalmers University of Technology, SSPA, Gothenburg, Sweden. Retrieved on February 10, 2020 from https://research.chalmers.se/publication/167457/file/167457_Fulltext.pdf.

White. C.M. (2008). Ergonomics: What is it? Clearing away the confusion. *The Bent,* Summer 2008, 24 – 27. Retrieved March 3, 2020 from https://pdfs.semanticscholar.org/2f9b/cbbbf556e4d48715ec6f62c488a0897a79d8.pdf.

10 Appendix I - Question pool for the workshops

These questions acted as be the base for the online workshops. Each research question has several sub-questions to help broaden the discussion. Since the sessions was semi-structured a question might be picked and asked if the moderator felt that the group was getting stuck with their reasoning.

- How does the engine crew perceive the work environment in the engine control room?
  - Do you feel that the task of the engineer in the control room has changed since you started working in the field? (if prolonged service record)
  - If so, do you feel that your work environment has adapted to these changes?
  - Do you feel that the design of the control room aids for a safe operation both in normal and extreme scenarios?
  - Would you consider it easy to get a quick and good overview of the plant/ship status when entering the control room that you are currently working in?
  - Do you consider the engine control room a good place to work in?
- What ergonomic consideration need to be taken into account to create a good work environment?
  - Can you list the top five most important ergonomic features according to your own preferences?
  - Would you consider the control room to be an ergonomically adapted work environment?
  - Do you or have you worked in a control room that you would consider to be good. If so, can you describe the general characteristics of that control room?
  - How would you like the important data to be presented to you?
  - Do you think that there are gaps in how the engine control room is designed? What are they, and how could it be improved/changed?
  - What do you think of the alarm system in the control room, would you like it to be different, and if so, how?
  - What is your overall impression of the control room, (on a scale of 1-5, where 1 is very bad, and 5 is very good...?)
  - Do current control room designs allow for an efficient work environment with more than one operator involved?
- Given one existing control room, how would its operators (you) redesign it for optimal ergonomics and function?
  - For this research question, one or two control room designs will be shown, and participants will be asked to optimize them to their liking.

DEPARTMENT OF MECHANICAL AND
MARITIME SCIENCES
DIVISION OF MARITIME STUDIES
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