Review

Human Factor Issues in Remote Ship Operations: Lesson Learned by Studying Different Domains

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Abstract: The idea of remote controlling ships for operational and commercial uses has developed beyond concepts. Controlling and monitoring vessels from a distant location requires updating the concept and requirements of shore control centers (SCCs), where human operators control the fleet via cameras, GPS, and many other types of sensors. While remote ship operation promises to reduce operational and maintenance costs, while increasing loading capacity and safety, it also brings significant uncertainty related to both the human-machine and human-human interactions which will affect operations. Achieving safe, reliable, and efficient remote ship operations requires consideration of both technological, cultural, social and human factor aspects of the system. Indeed, operators will act as captain and crew remotely, from the SCC, introducing new types of hardware and software interactions. This paper provides an overview of human factor issues that may affect human-machine and human-human interactions in the course of remote ship operations. In doing so, the literature related to remote operations in the domains of shipping, aerial vehicles, cranes, train transportation, automobiles, and mining is reviewed. Findings revealed that human factor issues are likely to fall into 13 distinct groups based on the type of human interactions that take place in SCCs.

Keywords: remote ship operations; human factor issues; human-machine interactions

1. Introduction

Existing technologies such as sensor technologies and artificial intelligence, as components of the Industry 4.0 revolution, have enabled maritime companies to implement an early prototype of remotely controlled ships. Remote ship operation can improve the efficiency of ship operation by implementing novel concepts, such as Industry 4.0, which will improve safety and performance. In addition, remote ship operation enables more cost-efficient shipping by reducing or removing onboard manning and providing the advantage of being able to operate multiple ships from a control center simultaneously. According to ship operating reports, manning related costs can constitute 25% of total ship operating costs [1]; therefore, reducing or removing onboard manning can reduce a considerable portion of ship operating costs.

Various players in the maritime industry are pursuing the implementation of remote ship operations. In 2017, Wärtsilä [2] tested maneuvering an 80 m platform supply vessel in Scotland remotely from United State via satellite link. Rolls-Royce and Svitzer also tested remotely maneuvering a 28 m tugboat in Copenhagen harbor by a captain on shore in 2017 [3]. However, remotely controlled ships are not yet fully developed and their future is unknown.

Remotely controlled ships interact and communicate with human-operated systems. In this way, human operators program voyage planning, navigation and continuously monitor the vessel from the shore control center (SCC) to avoid accidents. The onboard

systems follow well-established international regulations, whereas the implementation of SCCs is not standardized and companies develop their own SCCs.

Since human operators play a key role in monitoring and supervising remote ships from SCCs, human factors can significantly affect the performance and reliability of remote ships. On the other hand, remote ship operations are in the early stages and few SCCs have been implemented as a consequence of testing remote operations. Hence, investigating remote control experiences in different domains will help to improve the efficiency and reliability of SCCs in remote ship operations.

This paper investigates remote operations that have been implemented in different domains in the literature to identify the human factors that affect remote operations. In doing so, more than 50 articles were analyzed in order to identify factors that can affect remote ship operations; in particular, remote operations in SCCs. Then, inductive coding was utilized to categorize factors into human factors that affect human-human and human-machine interactions. As a result, 13 human factors were identified that can affect remote operations in SCCs, of which, three factors affect human-human interactions, eight factors affect human-machine interactions and two factors can affect both human-human and human-machine interactions.

The rest of this paper consists of three main parts. Section 2 presents the background and definitions, while Section 3 presents the methods used for the literature review. Section 4 classifies human factor issues identified in different domains. Finally, Section 5 concludes the study and mentions the limitations and future research directions.

2. Background

2.1. Remote Ship Operations

The process of teleoperation refers to the operation of a machine (teleoperator) at a distance such that there is continuous and direct human control of the machine [4]. In other words, teleoperation can be defined as the remote control of a vehicle by a human [5]. Remote ship operation is a process involving the control, manipulation, supervision, and administration of vessels from a distance, such that operators can collect vessels' operating information (e.g., fuel consumption and health status) from sensors and an onboard automated system.

Remote operations can be applied in different ways for different vessels. Table 1 provides a general overview of how remote operations cover and complete the operations of three types of vessels, including manned vessels, unmanned vessels, and autonomous vessels, inspired by [6] and by the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project. While most of the literature treats unmanned and autonomous vessels as identical; this paper distinguishes between these two concepts because only one of these types can have a crew onboard. Below, remote ship operation is explained in detail in relation to both of these types, and the role of human factors in relation to remote ship operations is described.

Table 1. Three types of vessels and remote ship operations.

Type of Vessel	Crew	Operation
Manned (conventional)	Onboard	Manned operation (remote operation could be utilized for some tasks such as crane operation)
Unmanned	Ashore	Autonomous execution and control, remote operation, wireless monitoring and control, satellite communication, etc.
Autonomous	Ashore—a few crew members could be on board	Autonomous execution and control, remote operation, wireless monitoring and control, satellite communication, etc.

2.2. Unmanned and Autonomous Vessels

The concept of unmanned vessels relies on the land-based shore control center (SCC) [6], where the crew will monitor the vessel using crucial information transferred by satellite communication at short time intervals. If the autonomous system registers a problem—in addition to in several other situations—the crew at the SCC will take remote control of the vessel [7]. Porathe et al. [8] explain unmanned ships as:

> "*An unmanned ship is a ship with no humans onboard. An unmanned ship does not have to be autonomous; it can be under autonomous control but it can also be under remote control from a [Shore Control Center], or from other places (e.g., a pilot or tugboat or a mooring supervisor).*"

An autonomous ship is defined as a ship:

> "*with modular control systems and communication technology to enable wireless monitoring and control, including advanced decision support systems and the capabilities for remote and autonomous operation*" [9].

Porathe et al. [8], explain that autonomous vessels have an automated software system that navigates and maneuvers the vessel. The system and the ship are under monitoring from the SCC. An autonomous ship has no crew in the engine room or bridge, but it may have a maintenance or service crew. The navigation and engine rooms have a programmed automatic system that typically reaches a particular level of artificial intelligence [7].

The MUNIN project describes the concept of an autonomous ship as a ship which is operated autonomously within specific limits by new systems onboard the ship. In this scenario, the functions of control and monitoring could be performed by operators in the SCC [10]. The crew continuously monitor the operation of the vessel from the SCC, implementing direct remote control in exceptional situations.

The operation of unmanned and autonomous vessels can be defined in four main states: autonomous execution, autonomous control (autonomous problem solving), remote control, and fail-to-safe mode [5]. Autonomous execution means that the onboard autonomous system constantly controls and measures the vessel's status to determine if the vessel can continue with its predefined plan. This involves providing regular data to the SCC so that the offshore crew can monitor the functioning of the vessel, while the SCC is not required to intervene, except in certain special cases. The vessel will enter into the autonomous control or autonomous problem solving states when a deviation from the predefined plan is required (e.g., crossing other vessels or harsh weather) [10]. At any time, the SCC can take remote control over the vessel and completely override the onboard autonomous ship controller (ASC) [5]. Fail-to-safe mode is the vessel's status if communication is lost and the autonomous system cannot resolve the problem [7].

2.3. Different Types of SCC Control Modes

Based on the control modes for unmanned and autonomous vessels, there are also different modes for the SCC. Rødseth et al. [5] argued that remote monitoring, remote operation, status investigation, ASC update, and intervention are the most important SCC control modes. During the remote monitoring mode, no action will be taken by the SCC and all ship status indicators are normal within the SCC. The SCC will enter into the ASC update and investigation mode when ship status indicators indicate an abnormality. During the investigation mode, the SCC operator will interact with the onboard system directly in order to obtain more details of the problem. However, during the ASC update mode, the SCC operator will update some aspects of the ASC plan [11]. When the ASC is not able to solve the problem, SCC will enter the remote ship operations mode. Furthermore, the SCC can be under intervention mode when more interactions with the onboard autonomous and navigation systems are required [5,11].

2.4. Human Factors in the Context of Remote Ship Operations

Human factors examine the way human capabilities affect the system. Understanding the human factors involved can optimize the performance and reliability of the overall system. Human factor analysis is a scientific discipline that deals with understanding the interactions between humans and other components of a system; it involves applying theory, data, methods, and principles to design and optimize human well-being and overall system performance [12]. Despite the many advantages of remote operations, including more efficient cargo space, more efficient fuel usage and more efficient usage of crew and their skills [13], the technology complicates the interaction with humans. For example, SCC operators must make a new mental model, in which they are blind to the environment in order to monitor and control the vessel from shore. This requires transforming the "*onboard mental model*" so that it can be transferred to the SCCs [7]. Notably, such mental model is an internal representation of conceptual and causal interrelations between components that people utilize in order to understand phenomena [14].

Most maritime accidents occur due to human error [10]. In this respect, Uğurlu et al. [15] discussed several studies, concluding that 80–90% of maritime accidents are attributable to human error. This is true in other types of operations as well. For instance, a study of 68 unmanned aerial vehicle (UAV) accidents found that 65% of the 287 causal factors were associated with a human being [16]. Rasmussen's [17] theory and human factors analysis and classification system-maritime accidents (HFACS-MA) discuss risk assessments and provide human factors that are directly related to accidents. The HFACS-MA framework categorizes the causes of marine accidents into five levels including unsafe acts, preconditions, unsafe supervision, organizational influence and external factors [18]. On the other hand, this paper considers that skill-based errors, mistakes and violations are factors that affect control centers, in accordance with the health and safety executive (HSE). In light of this, it is necessary to understand the role of humans in the context of remote ship operations and to distinguish different types of human interactions and human factor issues that are likely to arise.

The first question is whether humans play a vital role in particular functions. In remote ship operations, operators in the SCC have to respond to sensor information immediately, especially in the case of a hazardous situation. The human acts as a backup system when the autonomous system fails. Thus, the human in the loop acts as a critical sub-system which affects the performance of the whole system. This involves both human-machine interactions—as humans interact with the software and hardware in the SCC and respond to the sensor information—and human-human interactions, as the operators, situation team (captain and engineer) [19], and supervisor all work together on remote ship operation within the SCCs.

Relocating onboard humans to onshore control centers introduces new human factor challenges compared to the existing challenges onboard manned ships and these may impact ship operations differently. Burmeister et al. [10] and MUNIN project [20] argued that human operators involved in the SCC are as follows

- SCC operators monitor the operations of autonomous or unmanned vessels from the SCC. Operators can give high-level commands such as changing the voyage plan.
- SCC engineers assist the operators with the technical aspects of ship operation and oversee the maintenance plan.
- The SCC situation team can take over direct remote control of a ship via the Remote Maneuvering Support System of the bridge of the vessel, which provides situation awareness (SA) to the crew in the SCC.

The rest of this paper consists of three main parts. The next section explains the methods used in this study. The third section classifies the human factor issues in different domains. The fourth part presents the conclusion, the main limitations of the study, and areas for future research.

3. Materials and Methods

For this study, the literature was investigated in order to classify the main human factor issues affecting operating ships in shore control centers. In the current research, various databases including ScienceDirect, IEEE Xplore, and Scopus were searched for related peer-reviewed studies using keyword including "remote operations", "shore control center", "human factors", "autonomous vessels", "ship operations" and "unmanned ships". In addition, no publication time limit was considered while retrieving articles from digital libraries. The search domain was limited to the literature related to remote operations, teleoperations, human factors, human factor challenges, and automated environments. Search results were gathered in a non-structured way among industries that presented progress in applying remote operations. At the first stage, more than 50 papers were investigated, while during the second stage, the abstracts of the papers were investigated to select the most relevant literature to the topic. Finally, 38 papers that addressed the human factor issues of remote operations were selected in different domains in order to sharpen the literature review. This review primarily focuses on the operation of shore control centers, and therefore, issues relevant to the operation of remote ships in shore control centers were selected from the literature. This review also considered related work in regard to the shipping industry, unmanned aerial vehicles (UAVs), unmanned aircraft systems (UASs), remote operated cranes, self-driven trains, autonomous cars, and remote mining.

Results were analyzed based on an inductive coding process. Codes are constructs that are generated by the authors, which appear progressively through the qualitative data collection method. Codes are short phrases or words that are symbolically assigned to a portion of data [21]. The coding process in the present paper was conducted in two phases, including first cycle and second cycle coding. During first cycle coding, the author went through all gathered papers and identified empirically grounded codes which were related to human factors and the operation of automated systems. The portions of the data which were related to the mentioned fields were coded from a single code to a phrase. For example, fatigue, cultural problems, and linguistic problems. In this respect, the author developed a table including related portions of data and assigned codes in order to clarify, revise and identify final codes. During the second cycle of the coding process, the author grouped the first cycle codes into smaller categories and revised the codes to avoid overlapping. Finally, the author identified 13 codes, which are presented in the next section, as the main human factor issues. Additionally, during the second cycle of coding, the author developed pattern codes or meta codes. This refers to classifying the identified codes into bigger groups. In this respect, all 13 codes were classified into two main groups including human-human and human-machine interactions. These two groups indicate which human factor issues (codes) are related to human-human and human-machine interactions. Figure 1 presents our literature review methodology starting with analysis of the literature and continuing with the inductive coding process in order to classify the human factors affecting each type of human interaction in shore control centers.
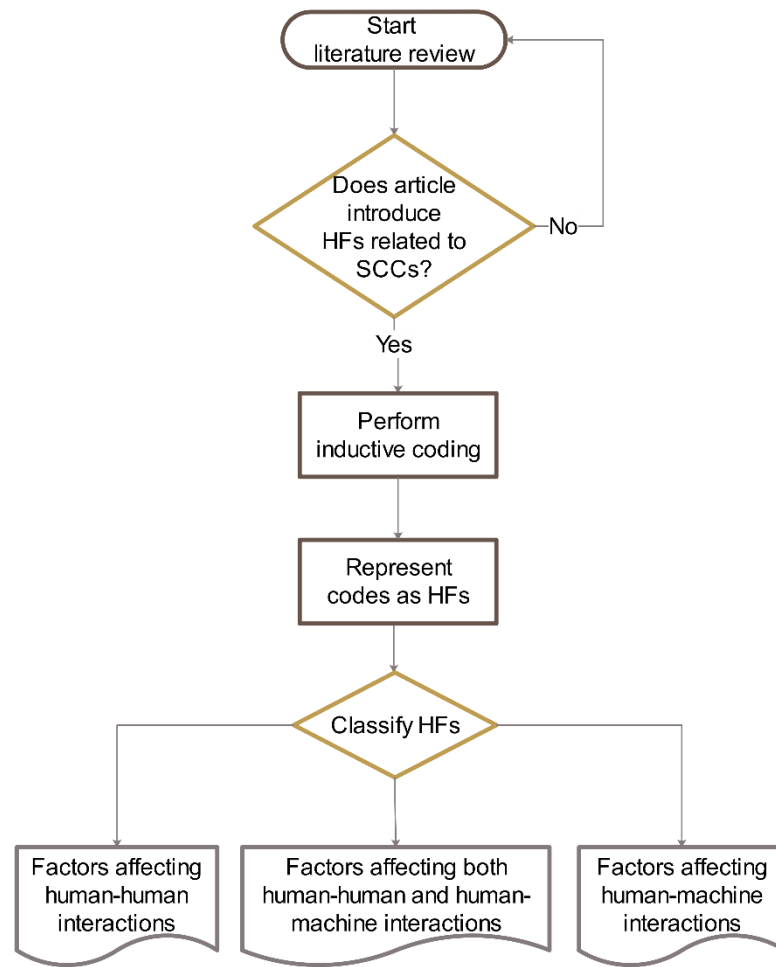
Figure 1. Process flow for identifying human factors (HFs) affecting shore control centers (SCCs) from the literature.

4. Results

The results of the literature review are classified as 13 main human factor issues which are shown in Table 2: (1) situation awareness (SA), (2) high workload, (3) trust, (4) boredom, (5) fatigue, (6) skill degradation, (7) human-machine interface, (8) lack of direct sensory information in the SCC, (9) communication challenges, (10) decision-making, (11) linguistic problems, (12) cultural problems, and (13) teamwork. These issues affect human-human and human-machine interactions. The sections below present the results of the each of these issues.

Table 2. Human factor issues in remote operations.

		Human–Machine Interactions								Human–Human Interactions				
Authors	Domain	1	2	3	4	5	6	7	8	9	10	11	12	13
Burmeister et al. [10]	Shipping	✓	✓					✓		✓				
Man et al. [22]	Shipping	✓	✓	✓				✓	✓	✓	✓			
Porathe et al. [7]	Shipping	✓	✓						✓	✓	✓	✓		
Wahlströma et al. [23]	Shipping	✓	✓		✓		✓	✓	✓	✓		✓	✓	
Man et al. [24]	Shipping	✓							✓		✓			
Xue et al. [25]	Shipping										✓			
Olenderski et al. [26]	Shipping										✓			

Table 2. *Cont.*

| Authors | Domain | Human–Machine Interactions | | | | | | | | Human–Human Interactions | | | | |
		1	2	3	4	5	6	7	8	9	10	11	12	13
IMO-NAV [27]	Shipping	✓						✓		✓				
IMO [28]	Shipping		✓					✓		✓		✓		
Kari et al. [29]	Shipping		✓	✓	✓		✓		✓	✓				✓
Zhang et al. [30]	Shipping	✓				✓					✓			
Wróbel et al. [31]	Shipping	✓						✓					✓	
Oncu and Yildiz [16]	Aviation (UAV)	✓	✓			✓	✓	✓	✓	✓	✓		✓	✓
Johnson [32]	Aviation (UAV)	✓	✓					✓					✓	
Nisser and Westin [33]	Aviation (UAV)	✓	✓	✓			✓	✓	✓		✓			✓
Williams [34]	Aviation (UAV)							✓			✓	✓		
Waraich et al. [35]	Aviation (UAS)							✓						
McCarley and Wickens [36]	Aviation (UAV)							✓	✓	✓				
Thompson et al. [37]	Aviation (Aircraft)				✓	✓								
Hobbs and Herwitz [38]	Aviation (UAV)								✓	✓		✓		
Drury and Scott [39]	Aviation (UAV)	✓						✓						
Endsley [40]	Aviation (Aircraft)	✓												
Lester and Thronson [41]	Airspace (telerobotic)									✓				
Baldwin [42]	Aviation (UAV)								✓			✓		
Karvonen et al. [43]	Remote operated container crane	✓	✓					✓	✓	✓				
Abdullah et al. [44]	Remote operated container crane							✓	✓	✓				
Abdullah and Handroos [45]	Remote operated container crane							✓	✓		✓			
Karvonen et al. [46]	Remote operated container crane							✓	✓					
Karvonen et al. [47]	Automated train)	✓							✓		✓			
Wahlström et al. [48]	Metro control center	✓												
Dadashi [49]	Rail intelligent infrastructure	✓	✓	✓				✓			✓	✓		
Saffarian et al. [50]	Automated driving	✓	✓	✓			✓							
Wahlström et al. [51]	Rally control center	✓		✓		✓	✓	✓						
Lynas and Horberry [52]	Mining		✓	✓			✓	✓	✓					
Lynas and Horberry [53]	Mining	✓		✓	✓	✓	✓	✓						
Number of articles address each factor		20	12	8	5	5	8	21	16	14	12	6	4	3

4.1. Situation Awareness (SA)

Endsley [40], defines situation awareness (SA) as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". Conception and cognition are two main key elements in achieving an adequate level of SA. SA has three levels: perception of the current situation, comprehension of it, and at the highest level, projection of the future situation [40]. Achieving levels two and three of SA (comprehension and prediction) is very critical for the performance of complex systems [33].

SA is commonly cited in human-automation errors. Aviation accidents and air traffic control errors frequently cite "*lack of SA*" or "*failure to maintain SA*" [33]. It is important to mention that lack of SA refers to a low level of SA in the environment. On the other hand, [22] discusses the relationship between harmony and SA in SCCs and discrepancies

regarding SA requirements. Man et al. [22] argue that "*harmony reveals the continuous balanced effect by tuning the ship to the dynamic environment under different situations that ship handlers strive for*". According to their findings, loss of harmony hinders perception and makes it harder to obtain the higher levels of SA in the SCC. In addition, they mention that operators in SCCs require more time to develop SA, after which they react.

Achieving a high level of SA requires an incremental process of collecting information from the environment. SA in SCCs does not only depend on information; it also depends on the dynamic of the operating situation, which chnages [7]. As sensors and satellite communications provide the required information for remote ship operations, the level of cognition and conception of the operators will lead to a lower level of SA in SCCs than they would have on board. This happens due to indirect sensory information within the SCC.

Various researchers who have examined SA argue that it should be considered in the case of land-based unmanned ship handling [22,48]. Furthermore, Porathe et al. [7] argue that misunderstandings a vessel's situation, which is an SA challenge, can lead to mistakes in SCCs. Similarly, the operator of a remote crane must know the exact location of each container. As researchers note, remote operators cannot automatically gain the same information as a conventional crane operator [43]. In another example, the automation of the Helsinki Metro rapid transit system was cancelled due the fact that, without an intrusion detection system, it will crash into a person or another object on the track. Other challenges researchers identified include "*driving the train on the track*", "*stopping at a station*" and "*interactions of the driver with other actors in the metro system*" [47]. These issues refer to a lack of an adequate level of SA within the control center about the train and its surroundings and a lack of direct sensory information during the operation of automated trains, similar to the operations of autonomous vessels at sea. The report of the 58th session of Sub-Committee on Safety of Navigation (NAV) [27] also references SA in its discussion of various user gaps and preliminary potential solutions for the operational areas of e-navigation solutions; some of the solutions identified could possibly also be applied in the field of remote ship operations, for example, an integrated presentation of available information. Research has identified a lack of harmonized presentation of local information in order to increase SA for shore support services for remote ship operation [10]. In addition, future research can leverage machine learning techniques to assess the risk of e-navigation using performance parameters collected from e-navigation systems and human factors that resulted in accidents. In doing so, a machine learning model can predict the risk of human operations based on the way they use e-navigation systems. Zhang et al. [30] provide a model of human error assessment for an autonomous cargo ship, which highlights the effects of situation awareness and ship perception as two significant factors. This issue is related to the way that sensor data are presented in order to provide local information for both monitoring and controlling processes in SCCs. Thousands of sensors provide information about the ship's status and voyage plan, however, the indirect sensory situation still remains, in addition to the fact that operators are not present onboard. This highlights SA as a significant challenge within the SCC.

It is important to mention that SA—in the current paper—is discussed based on human-machine interactions. Other domains included here, such as UAV operation, show a similar focus [39]. However, SA could be investigated based on human-human interactions as well. In this respect, it is necessary to focus on the interactions between SCC operators, the captain and engineers in order to investigate how these human interactions affect the level of SA. SA based on human-machine interactions could consist of the level of awareness of operators about the status of the unmanned or autonomous vessel, their surroundings, and also other vessels. This status comprises a wide range of factors including the ship's health and route plan. Overall, SA, as an important factor, should be considered from both human-human and human-machine interaction perspectives in order to gain adequate information and achieve a satisfactory level of SA within the SCC.

4.2. High Workload

Human workload is the sum of the all task demands which are imposed on operators and the subjective response of the operators to those demands [33]. According to the organization of SCCs, one operator could be assigned to monitor more than one vessel (up to six vessels) [54]. In this situation, operators have a higher level of workload than operators onboard. This challenge is derived from human-machine interactions. The remote system constantly provides information to provide an optimal level of SA, which increases the risk that operators will experience information overload and a high level of workload in monitoring many different systems.

Man et al. [22] state that an SCC can present all of the information operators need and would have if they were onboard, but note that if this is the case, then the observation of multiple screens and simulators would lead to information overload. Other research studies have highlighted that information overload has two main reasons: (1) a constant flow of information designed to maintain SA, and (2) the fact that operators might be overseeing several ships at the same time [7]. Porathe et al. [7] also point out that human errors may occur because of the "*carry over effect*" when one operator monitors more than one vessel at the same time. These situations refer to higher mental workload as an important human factor challenge within remote control centers.

Furthermore, one of the major predictors of procedural error in the operation of UAVs is operators' workload [16]. Increasing pilots' workload was a cause of the Nogales UAS accident [32]. Nisser et al. [33] found that automation alters workload by decreasing manual load and increasing mental workload. In addition, in the field of crane remote operation, one study found that the tasks can be different every time without any previous information about its operation. Hence, the operators must be able to reorient immediately on a received task [43]. This refers to operators performing multiple tasks in control centers, which creates a high level of mental workload.

The research reviewed here suggests that SCC workers could be exposed to too much information, which would make it impossible for them to understand the conditions of a ship they are overseeing. On the other hand, Saffarian et al. [50] discuss that insufficient and poorly designed automation leads to an erratic rise in operators' workload, which has to be considered in the design of SCCs. In this case, a poor design may provide unnecessary information which could lead to an erratic increase in operator's workload, and finally, leads to a higher level of mental workload.

4.3. Trust

Researchers have discussed the possibility that the use of automation is likely to increase if humans' trust in systems increases. The perceived reliability, or trust, can be affected by operators' prior knowledge about the level of reliability, knowledge of the automation capabilities, and automation reliability [55]. Research suggests that if interactions between humans and machines become more similar to interactions between humans, teamwork between automated systems and humans will be more effective. Nisser et al. [33] suggest that operators' trust in automation is the main factor affecting human-machine teamwork.

In the field of remote ship operation, operators have to trust the sensor information, the autonomous system, and the remote controlled systems. Man et al. [22] discuss the need to ensure these systems are completely reliable so that operators will trust them completely. This raises the question as to how systems can engender such trust and how much trust is appropriate. Saffarian et al. [50] found that drivers who use adaptive cruise control over-rely on the system because they put excessive trust in it. A similar situation is possible with remote ship operation.

Kari et al. [29] considered the factors that affect the operators' trust in systems. They found that training programs affect the trust between operators and the automated system, suggesting that SCC operators should be trained well. On the other hand, high reliance on autonomous systems and sensor information over a long period of time leads to skill

degradation. This issue requires attention because humans will act as a backup system even for ships with the highest level of autonomy.

4.4. Boredom

SCCs operators have to look at screens for several hours, which can lead to a high level of boredom. A study of operators of remotely piloted aircraft [37] found that 92% reported "*moderate*" to "*total*" boredom compared to 62% of sensor operators. Likewise, Wahlström et al. [23] highlighted boredom as a human factor challenge for unmanned ship operations.

4.5. Fatigue

A study that assessed fatigue indicated that UAV teams consisting of a pilot, sensor operator, and maintenance personnel show greater levels of fatigue than the crew of a manned aircraft [16]. However, another study found that operators consider remote monitoring and the shore control of unmanned vessels as a process full of "*compliancy and relaxation*". This study also highlighted that information overload is a problem [22].

Research on automated cars and automated driving shows that automation leads to a reduction in drivers' workload, but this leads to passive fatigue among drivers, leading to a reduction in overall performance [56]. Remote ship operators are also at risk of active and passive fatigue. Desmond et al. [57] describe active fatigue as a situation which "*is derived from continuous and prolonged, task-related perceptual-motor adjustment*". Active fatigue was highlighted by Saxby et al. [58], as a state which is associated with high cognitive workload. This situation can occur within an SCC during situations involving monitoring more than one vessel, accidental situations and high levels of workload. On the other hand, Desmond et al. [57] argue that "*passive fatigue appears over several hours of doing what appears to be nothing at all*", especially during system monitoring. This situation implies that SCC operators can be exposed to passive fatigue when SCC is only under the monitoring mode or they just monitor one vessel without any specific activity. The human-machine interface is another key factor in this field; for example, using multiple screens and insufficient furniture could also lead to a higher level of fatigue. In addition, Zhang et al. [30] argue that excessive fatigue is an important factor that leads to failure in emergency response processes.

4.6. Skill Degradation

Using autonomous systems over a long period of time may cause the operators' skill to degrade. A study of UAV operations highlighted this, stating that complacency and overconfidence are the main problems that experienced operators can have [33]. Operators who execute the same job for a long time think that they can perform the procedures and checklist operations by heart, which can lead them to miss a significant step in emergency situations and can blind them to hazards [16]. This situation refers to skill degradation in an automated environment over a long period of time, similar to automated driving and automated mining domains.

Remote ship operators are at similar risk of skill degradation. During remote and autonomous operations, vessels are under constant human control and monitoring. Hence, a human is in the loop in all modes of unmanned and autonomous operations and may take full direct remote control over the ship even at the highest level of autonomy. This implies that humans must always be prepared to take over operations. However, high reliance on autonomy for a long period of time degrades operators' skills.

4.7. Human-Machine Interfaces

Generally, human-machine interfaces are an important factor supporting proper decision making in automated systems, introduced by the industry 4.0 concept to improve work conditions and enhance productivity. Hence, human-machine interfaces should provide collected information to the operators in the most user-friendly way possible [59]. In SCCs,

human-machine interfaces mostly refer to ergonomics. The organization of SCCs significantly imperils good ergonomics. The size and number of screens and design of automated and remote systems directly affect operators' performance. Waraich et al. [35] proposed four subcategories of ergonomically acceptable collaborative work systems that exist in SCCs: installed systems, input devices, furniture, and visual displays. Indeed, during the remote operation of UAVs, the operator interface is defined as a preliminary facilitator of human-machine interactions and coordination, in addition to human-human communication and coordination. Smooth UAV operation requires an interface which provides an adequate level of awareness, aimed at reducing information overload, miscommunication, distractions, and coordination breakdown [39].

A study comparing various human-machine interfaces to onboard ship-handling equipment found that participants considered SCC simulators to be ideal human-machine interfaces because they use a joystick handle rather than a mouse. Participants suggest that the use of simulators as a human machine interface in SCCs would provide a 3D visualized environment in order to improve ship sense. However, researchers found that such a visualization would not provide adequate SA [22]. Wahlstrom et al. [23] discuss various solutions which could be applied in SCCs, such as a "*large shared display*" and "*shared screen*" that could be utilized in order to maintain shared awareness.

The 58th Sub-Committee on Safety of Navigation (NAV) session [27] prioritized various solutions to improve e-Navigation processes, such as improving and harmonizing bridge design to make it more user-friendly and the presentation and integration of available information in graphical displays which were received from communication facilities. Burmeister et al. [10] and international maritime organization (IMO) [28] highlight the same human-machine interfaces issues. These solutions are also critical in the design of SCCs because when humans start to interact with machines, an inefficient human-machine interface may lead to various human factor challenges such as a higher level of fatigue, greater communication challenges, and distraction from navigational and monitoring tasks.

4.8. Lack of Direct Sensory Information

Industries are investing in smart technologies and are deploying sensor networks to collect data for supporting decisions. Nardo et al. suggest leveraging the industry 4.0 concept to collect data about the health status of equipment to predict safety incidents and avoid possible accidents [60]. In remote ship operations, there is no direct, physical connection between the ship and operator, and operators receive no direct information from the vessel's surroundings. This may lead to a loss of kinetic feeling and visual perception [22]. This lack of direct sensory information is one of the important human factor challenges in the field of remote ship operation. Porathe et al. [7] stated that ship sense is not only about the collection and use of presented information by the navigational equipment. Furthermore, they wrote that some tasks are mainly visual, for instance navigating in close proximity to other objects or harbor maneuvers. This refers to the challenge related to the lack of direct sensory information during remote ship operation via the SCC. This factor primarily affects SA.

Studies in other domains also reference the lack of sensory information. A study of UAV operations identified distance and the resulting loss of sensory information about obstacles as factors that hinder optimal human performance [16]. Studies of remote container crane operations also highlight this challenge [43,45].

4.9. Communication Challenges

A reliable communication system is a significant challenge in SCCs, and misunderstandings—especially in interactions with the crew of other ships—might occur due to lags in very high frequency (VHF) communication, poor communication links, and language issues [7].

Man et al. [22] found that SCC operators observe a gyro and other sensors in shore-based unmanned ship handling, but the question is, are these sensors in real time? A

concern for separation between operators and vehicle is data transmission delays, which lead to delays in operators' responses. A study of UAV operation discussed time delays during communication between operators and UAVs which could affect operators' feedback [36].

A study of the use of a telerobotic for space discussed the issue of communication latency due to the large distance. This latency refers to the time delay between the human brain, sensor and telerobotic effector [41]. This problem can be applied to SCC operations. Immediate operation of the ship can be challenging due to the long distance of communication; although the distance on the earth is less challenging than in space [23].

Another form of communication is strictly human-human. Remote operators might not understand the local people, patterns of activity, their aims, or even their language, which leads to problems in some situations [23]. Language skills have been identified as essential for operators in e-navigation processes [28]. Linguistic problems are likely to arise during remote ship operations due to operating the vessel across long distances.

The 85th session of IMO [28] identified robust and effective communication between ship and shore as being a significant requirement among high level users in the field of e-navigation. Researchers found that effective communication between vessels and the shore reduces linguistic challenges and distractions of operators. In a study of the communication between ship, shore and shore support, officers were distracted from their navigational tasks due to extreme reporting requirements during e-navigation. They should avoid double reporting and harmonize all these communications; this leads to more time for navigational tasks in order to increase safety. On the other hand, most of the officers preferred to use broadband satellite communications for ship-shore communications to keep VHF communications free for emergency safety communications [10].

The review of the literature on communication challenges suggests that sensor information in the SCC should be harmonized in order to avoid distracting operators from their monitoring and controlling tasks; this issue affects operators' responses, especially in emergency situations. Just as operators prefer to keep VHF channels free for emergency safety communications, SCCs require specific communication channels between the ship and shore to increase safety, especially for ships in the fail-to-safe mode. It is clear that SCCs should utilize wireless and satellite communications in order to communicate and control the vessels. The technical aspects of implementation may be complex, but it is vital to manage and harmonize these communications in SCCs in a way that prioritizes human-machine interactions. It is notable that the quality of communication channels in SCCs affects the level of SA and the process of decision-making as well.

4.10. Decision Making

This human factor issue is derived from both human-human and human-machine interactions. Different types of technology, human-machine interfaces, communication channels, level of situation awareness, and sense of ship affect the process of decision-making. Man et al. [24] discussed challenges and gaps that prevent teams and individuals from gaining appropriate SA in order to make decisions during the remote monitoring and controlling of unmanned ships. A study of UAV operations showed that obstacles to understanding the situation in hand led to poor decisions [33].

On the other hand, the onboard autonomous system has to provide adequate information for operators in SCCs because operators' decisions depend on the provided information. For instance, one study drew attention to the problem that SCC operators may pay attention to information that is wrong or does not matter, wasting energy [22] and, hence, making poor decisions.

A study of remote ship operation argued that "*intelligent decision-making capability*" is a key element in automatic simulation systems and automatic ship navigation systems, which affect collision avoidance maneuvers and the planning of routes. In traditional maritime navigation, a human pilot is responsible for assessing the situation and making the safest decisions, while an automatic ship navigation system is designed for autonomous

navigation in a safe and efficient manner without human intervention or to guide navigators' decisions [25]. Danial et al. [61,62] implemented a Markov logic network to model SA primarily for fire accidents and the emergency evacuation of offshore platforms. Through doing so, software agents created a method of simulating different behaviors in different situations in order to improve decision-making by facing trainees to different situations in a virtual training environment. Smith et al. [63] proposed a methodology to capture the knowledge of expert seafarers and establish a knowledge database to improve decision making capabilities by providing the best operating practice for offshore ice management. They stated that seafarers make the decision and choose their strategy based on different techniques and prescribed approaches they learned from training. This indicates how the operator's decisions are derived from situation awareness and local information which they gathered during the operations. However, in remote ship operations, decision-making occurs specifically in control centers.

Another study identified the challenges of creating a successful training simulator in order to train conning officers. One of the main challenges is the "*readiness of response*" of the automated boats when they face new situations which require controllers to act in real-time when they carry out the assigned task [26]. Actions in real time could be affected by different factors, although, ultimately, this leads to a real-time decision. Thus, human-machine interactions and response times are also important in the context of decision-making for unmanned and autonomous vessels.

The quality of human-human interactions between operators, supervisors and the situation team also influence the process of decision-making. When the autonomous vessel switches to full direct remote control, situation awareness and human interactions within the situation team significantly affect decision-making processes. Factors such as stress, memory limitations, and a dynamic environment could very easily disturb decision-making and human cognitive work [33]. Furthermore, Porathe et al. [7] discussed delays that may occur due to SCC operators taking a long time to find out what is happening; this refers to the human-out-of-the-loop syndrome which affects the decision-making process. In another study, some remote crane operators explain that in unexpected situations, they stayed calm before making a decision [45]. Overall research implies that operators' decision-making is a process that is affected by both human-human and human-machine challenges during remote ship operations.

4.11. Cultural and Linguistic Problems

Communication challenges and misunderstandings during the interaction between autonomous and unmanned vessels with manned vessels might occur due to bad communications [7] and the organizational climate. This issue was highlighted by Wróbel et al. [31] as a working atmosphere which comprises structure, policies and culture within the organization. The organizational climate, which refers to the atmosphere of the organization which encompasses relationships, cultures, policies, and command and control structures. Past research suggests that problems with organizational values and culture have led to UAV accidents [16,64].

Making and protecting a human-centric culture is the way to create a peaceful atmosphere in an organization [16,64]. The study of the Nogales UAS accident showed that a culture of "*working around*" previous failures was a factor. This culture led to the poor documentation of maintenance procedures, which created a lack of adequate information about the corrective process [32]. In relation to UAV operation, [38] a "*model aircraft culture*" was identified, in which radio control hobbyists usually perform operating and maintenance processes without formal checklists or procedures. They conclude that this culture must be changed if hobbyists are to join the UAV industry through the provision of training to change their habits and work culture.

The research suggests that cultivating an effective culture and sufficient linguistic skills among the teams that operate in SCCs is vital for the safety of remote ship operation. Whereas onboard crews travel based on the voyage-plan and are more familiar with differ-

ent cultures and languages, remote ship operations will confront cultural and linguistic challenges that are not present in onboard operations.

4.12. Teamwork

Teamwork is the product of human-human interactions between operators, supervisors, and the situation team inside the SCCs. It includes the integration between attitudes, knowledge, and certain skills that leads to members adapting and optimizing their performance [33]. According to Kari et al. [29], human interactions between operators affect the whole performance of a remote control system in both a positive and a negative way. A study of UAV accidents highlights the role of crew/team leadership and supervision. Supervisors are responsible for guidance, leadership, motivation, steering team members toward training opportunities, and serving as effective role models. Researchers argue that UAV operators make more mistakes if supervisors fail to obtain these goals [16]. It seems likely that teamwork and supervision play an important role in SCCs.

Various factors, such as the organizational culture, may also affect the performance of teams. Team performance has a direct relationship with the process of decision-making, in that SCCs are organized such that operators monitor ship operations and engineers assist them, when required. Furthermore, in remote control mode, the situation team take direct remote control over the vessel. Hence, teamwork is another significant human factor issue in the field of remote ship operations.

4.13. Relationships between Human Factor Issues

Table 3 presents relationships between human factor issues in the context of remote ship operations and how these issues affect each other and human interactions. It highlights decision-making as a human factor issue that is highly integrated into the context of SCCs and reflects the impact of other human factor issues. In Table 3, only the human factors that affect each other are presented. The negative and positive relationships between these issues are identified as well. Some human factors can have both a positive and a negative effect on each other. For instance, good teamwork via effective work with team members, commitment to team processes and success [65]—derived from high-quality human-human interactions—can positively affect the different aspects of decision making. In this respect, good teamwork does not include jealously [66] between the SCC operators, captain, and engineers, is centered around improving communication and takes all team members seriously [66]. On the other hand, poor teamwork can lead to poor decisions within an SCC.

Table 3. Relationship matrix (relationships between human factor issues).

	SA	Teamwork	Skill Degradation	High Level of Workload	Communication Challenges	Decision Making
SA						Low level of SA has a negative effect on decision making
Teamwork						The efficiency of teamwork can affect the decision making process both negatively and positively

Table 3. *Cont.*

	SA	Teamwork	Skill Degradation	High Level of Workload	Communication Challenges	Decision Making
Skill Degradation						Skill degradation affects the decision making negatively
High Level of Workload						High workload affects the decision making negatively
Boredom						Operator's boredom affects the decision making negatively
Communication Challenges		Communication challenges have negative effect on teamwork				Communication challenges affect the decision making negatively
Lack of Direct Sensory	Lack of direct sensory information affects the level of SA negatively				Lack of direct sensory information leads to communication challenges between shore and ships	Lack of direct sensory information has negative effect on decision making
Human machine Interfaces	Inefficient human-machine interface affects SA negatively, however, efficient human-machine interfaces affect SA in a positive way.			Inefficient interfaces affect workload negatively, efficient interfaces affect workload positively	Inefficient interfaces affect communication negatively, efficient interfaces affect it positively	The efficiency of the human-machine interface affects decision making positively and negatively
Fatigue						fatigue affects decision making negatively
Cultural Problems		Cultural problems affect teamwork negatively				Cultural problems affect the decision making negatively

Table 3. *Cont.*

	SA	Teamwork	Skill Degradation	High Level of Workload	Communication Challenges	Decision Making
Linguistic Problems		Linguistic problems affect effective teamwork negatively			Linguistic problems increase communication challenges	Linguistic problems negatively affect decision making
trust			High trust leads to skill degradation over long period of time			High level of trust affects the decision making in a negative way

The authors analyzed the literature and extracted the relationship between human factors. This information can provide knowledge in relation to the importance of each human factor and, therefore, it could form a baseline for future studies. For instance, the quality and design of human-machine interfaces can affect the level of SA, workload, communication challenges and also decision making. Robert et al. [66] highlighted suitable data presentation at the human-machine interface as one of the technological aspects of decision making. This implies that good design and efficient human-machine interfaces may solve a wide range of problems regarding communication, workload, level of SA and decision making.

As seen in Table 3, a lack of direct sensory information leads to a lower level of SA. On the other hand, low level of SA and a lack of direct sensory information negatively affect the technological aspects of decision making [66]. It is clear that a high workload is one of the most significant factors that increases the operators' fatigue, while it also has a negative effect on certain aspects of decision making. Linguistic problems are another human factor issue that increase communication challenges, and finally, negatively affect the operator's decisions due to a lack of communication skills, misunderstanding or having no meaningful interpretation of the meaning of the words. This is highlighted by [66] as one of the human aspects of the decision-making process. Skill degradation as a consequence of the high level of trust in automation is another factor that leads to inefficient decisions in control centers. Culture is another human aspect of the decision-making process which can affect the operator's decisions. The quality of decisions, especially within a team, depends on the culture. For example, an individual may act according to his/her own experience, high ranking people, friends, or the regulations given [66]. Finally, a level of high reliance and trust in automation may result in procedural errors or out-of-the-loop syndromes that can lead to irrational behavior and inefficient decisions. In this respect, Robert et al. [66] refer to Sheridan's idea that individuals require trust for rational behavior, decisions and acceptance of automation.

5. Conclusions

Remote ship operations eliminate the role of humans in guiding ships on board, but they do not eliminate the human factors involved in monitoring and even—when necessary—controlling them, as human operators provide these interventions from the SCC. This paper provides insights for the design of SCCs and the understanding of humans as a critical sub-system in the context of remote ship operations. Remote operators have to gain an adequate level of SA and sense of ship during monitoring and controlling the vessel in order to make effective decisions. Hence, onboard autonomous systems need to provide updated data to the SCC via sensors and satellite communications, which leads to other human factor challenges such as communication problems, latency, lack of direct sense of ship and higher workloads compared to onboard operations.

Current forums of autonomous and unmanned vessels state that operators in SCCs will be assigned to monitor more than one vessel. While the situation team would take full direct remote control of one vessel in specific situations, operators would be exposed to a high workload, which is a human factor issue in need of greater attention. On the other hand, it is clear that the working environment in the SCC is completely different from the traditional onboard bridge and there is no direct connection between the operators and the vessel. SCC operators rely on sensor information and only onshore instruments; they have to work with screens and new types of interfaces. This implies the importance of human-machine interactions and how human-machine interfaces affect the operator's behavior. Additionally, human-machine interfaces have a direct effect on the level of operator's boredom and fatigue in addition to workload and working hours.

Trust in the SCCs is another human factor issue; the main challenge is operators' trust in sensor information and eliminating factors that negatively affect the operators' trust. On the other hand, a high level of trust over a long period of time leads to another human factor challenge, namely skill degradation. Situation team operators must be able to take full remote control over the vessel when needed, but this is infrequent. Decision-making and teamwork also influence the process of monitoring and controlling the vessel in SCCs. Other human factor issues affect decision-making both directly and indirectly.

The 13 identified human factor issues in the current study are as follows:

- Situation awareness (SA)
- High workload
- Trust
- Boredom
- fatigue
- Skill degradation
- human-machine interfaces
- Lack of direct sensory
- Communication challenges
- Decision making
- linguistic problems
- Cultural problems
- Teamwork

Most of the human factor challenges have been identified based on suggestive models and qualitative research conducted in remote control domains. Although few human factors have been tested in the real world with large and quantitative samples, this study provides a new perspective for human factor models, and future research should address experiments in the real world with large samples. In addition, this study focused on human factors affecting operations of shore control centers, which can be extended to investigate human factors affecting the safety of remote ship operation. Simulator experiments will also help to assess and evaluate the role of human-machine and human-human interactions, and the impact of each human factor issue. Additional research should also be conducted to identify methods for addressing problems related to human factor issues in SCCs.

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