Functional Requirements for Onshore Operation Centers to Support Remotely Operated Ships

Muhammad Adnan[1], Lokukaluge Prasad Perera [1,3], Hasan Mahbub Tusher [2], and Salman Nazir [2]
[1]Department of Technology and Safety, UiT The Arctic University of Norway, 9019 Tromsø, Norway
[2]Faculty of Technology, Natural and Maritime Sciences, University of South-Eastern Norway, 3184, Horten, Norway
[3]SINTEF Digital, SINTEF AS, Oslo, Norway

ABSTRACT

Autonomous shipping has received extensive attention from the maritime industry as well as the respective research, academic and training institutes, owing to its major benefits related to cost and safety over traditional shipping in many situations. In reality, the implementation of autonomous technology in shipping can face numerous challenges from the technology and regulatory perspectives. Adopting onshore operation centers (OOCs) for monitoring and control support is envisaged to alleviate these challenges and assist in obtaining broader acceptance of autonomous navigation from the maritime industry. The primary role of OOCs is to provide monitoring, guidance, and support for autonomous vessel operations from navigational and operational perspectives through remote human operators. Advanced sensors, communication technologies, and AI-based algorithms are envisioned as the foundation of OOCs to support remotely controlled operations. These centers enable remote human operators to monitor and control the vessels from onshore, i.e., without being physically present on the ship bridge. To develop OOCs that can provide support for autonomous ship operations, i.e., remotely in critical navigation situations, there is a need to identify its navigational, and operational requirements, i.e., functional requirements, and that has been the main contribution of this study. These functional requirements can further be considered under remote control technology that is available in both onboard ships and onshore OOCs. The technology, navigational, and operational requirements are identified as the main functional requirements for OOCs and that can be significantly different from the traditional shipping industrial technologies and operations. To implement robust monitoring, guidance, and support applications in OOCs, essential requirements must be identified according to the needs of remotely controlled ships, as discussed in this study. Furthermore, these functional requirements of OOCs, i.e., technology, navigational and operational requirements, are further discussed with respect to key pillars of autonomous shipping, i.e., technology, human-AI interactions, and regulatory aspects of shipping.

KEYWORDS: Autonomous ships; Remotely Controlled Vessels; Onshore Operation Center (OOC); Functional Requirements; Ship Navigation; Ship Operations.

INTRODUCTION

Autonomous shipping can change many operational and navigational requirements of the shipping industry. Even though there are various industrial-level research projects are implemented towards autonomous shipping, the outcomes of such projects not visible in the shipping industry. Furthermore, there is a lack of robustness in navigational and operational conditions of autonomous ship operations, where future vessels should operate without the presence of human operators, which has not been addressed by such projects. To ensure the safety of ship navigation, onshore operation centers (OOCs) are envisaged as adequate solutions to overcome possible challenges faced by autonomous ships from both navigational and operational aspects while respecting the regulatory requirements of the maritime industry. That discussion is the main contribution of this study. Autonomous vessels are required to operate and interact in highly dynamic operating environments, i.e., harsh weather conditions with nearby vessels. During such vessel operations, robust system monitoring with redundancy is primarily emphasized to reduce the risk of possible ship system failure (Johansen et al., 2023). Such robust system monitoring can be done by OOCs, therefore it is necessary to satisfy the functional requirements for monitoring and controlling future ships.

Intelligent sensors, AI-based algorithms, and control technology enable the concept of autonomous shipping and remote-control operations to become a reality in multiple domains, where complex processes or operations can encounter higher risk in harsh environmental conditions. The primary objective of establishing OOCs is to support hazards and optimize operational capabilities, particularly when autonomous navigation and operation system failure situations occur. These OOCs can usually provide facilities to address operational and safety challenges in harsh ocean environments while ensuring greater safety conditions for human operators. OOCs can be utilized across diverse sectors, such as oil and gas, aviation, steel manufacturing, and cement industries, which have demonstrated high dependability and practicality in their operations (Tyberø et al., 2023).

Rapid technological advancements supported by machine learning and AI applications have introduced a significant transformation in various industries, including the maritime sector. The advent of remotely controlled navigation may lead to the development of new avenues for vessel operations, offering potential benefits in terms of efficiency, safety, and operational flexibility as a part of the same transformation. Advanced automation technology has also supported altering shipping operational scenarios in multiple ways, such as autopilot, remote control through OOC, fully autonomous operations, etc. Advanced sensors and control systems can support human operators to execute remote ship operation tasks adequately. Therefore, combining human capabilities with advanced remotely controlled technology has the potential to make autonomous ships more robust and safer (Lee, 2008; Parasuraman, 2000), specifically in critical situations, e.g., possible system failure situations. It is expected that the next generation of autonomous ships should be operated and monitored through OOCs for the same reasons (Alsos et al., 2022). Therefore, determining the functional requirements of human interaction with these automation technologies for OOCs is crucial and is the main contribution of this study.

Intelligent AI-based algorithms can make smart decisions by extracting relevant information from the data. Such algorithms can also be utilized for decision-support systems by utilizing the existing maritime rules and regulations. However, such decision support systems may require extensive evaluation in realistic ocean environments to quantify their trustworthiness (Namazi et al., 2023), i.e., to ensure enhanced reliability, safety, and security in ship navigation (Komianos et al., 2018). Decision support systems can potentially reduce human error; however, that may create new challenges; therefore, such systems' trustworthiness (Namazi et al., 2023) should be quantified further (Rolls-Royce et al., 2016).

Some research studies have proposed that the development of the OOC and autonomous shipping should be performed gradually incrementally; therefore, an adequate period for humans to be familiar with the respective technologies can be achieved (Kooij et al., 2022). The human crew is expected to be replaced by OOCs during autonomous ship navigation. To achieve this objective, a systematic approach is necessary in the shipping industry, in which tasks with an optimal combination of benefits are replaced in a logical order. Deploying and implementing step-by-step autonomous technology development and integration can help the shipping industry understand the respective challenges, including the operational conditions of the OOCs.

The goal of the OOCs is to replace the humans on broad to onshore locations for possible ship monitoring and operational activities. To design an OCC with operational capabilities of autonomous ships safely and efficiently, further research and development steps are necessary, which can enhance an appropriate operator interface for remote-control purposes of future vessels (Jing et al., 2020). Irrespective of autonomous ships and their technologies, human operators in OOCs will always play a critical role in monitoring and handling emergency situations in possible ship system failure situations. Therefore, in the OOCs, it is required to integrate an appropriate human-machine interaction (HCI) capabilities in the design phase for a more robust remote monitoring and control approach toward future vessels (Veitch et al., 2021).

Artificial intelligence and advanced data science significantly alter the nature of seafarers' jobs and ease the ship operation's handling, from ship captains to press-button operators. In future control design, which is usually based on a human-in-loop system where the autonomous system will handle the majority of the navigation functions, human operators only intervene in case of emergency or something goes wrong (Veitch et al., 2022). Finding such actual functional requirements in remote control autonomous shipping still faces challenges owing to the unstructured maritime operating environment and the initial stage of the implemented technology in the maritime domain (Dybvik et al., 2020).

Remotely controlled navigation can refer to the ability to operate vessels from an onshore location using advanced communication and control systems. This technology can also enable remote operations of Maritime Autonomous Surface Ships (MASS), wherein human operators can oversee and control vessel operations with manned or unmanned conditions. To design such a robust remote-control framework, it is necessary to investigate the functional requirements of the OOCs regarding navigational and operational requirements from the perspective of technology, human-machine interactions, and regulation. This study delves into the navigational and operational requirements under the technology, human-machine interactions, and regulation perspectives towards remotely controlled ships by focusing on its implications for the maritime industry as the first section of this study. The second section discusses the methodology, the third section covers functional requirements, and the fourth section concludes the study.

METHODOLOGY

The purpose of this study was to explore the functional requirements, including the navigational and operational aspects under the technology, human-machine interactions and regulation perspectives associated with remotely controlled ship navigation of MASS, as mentioned before. This study aims to provide insights into key considerations for developing safe and effective remotely controlled navigation and operation technologies for the maritime industry by examining the exact requirements specific to MASS-defined levels. This study analyzes navigational and operational requirements regarding technology, human-machine interactions, and regulatory perspectives, as shown in Figure 1. By understanding these requirements with respect to the stakeholders in the maritime industry, they can make appropriate decisions regarding the implementation and integration of human crew and remotely controlled technology in future ship operations.

To support the analysis, this study draws upon a variety of maritime authorities (e.g., IMO) and industry and classification society guidelines (e.g., DNV guidelines related to MASS and ABS reports), offering valuable insights into the navigational and operational requirements in the aforementioned context.

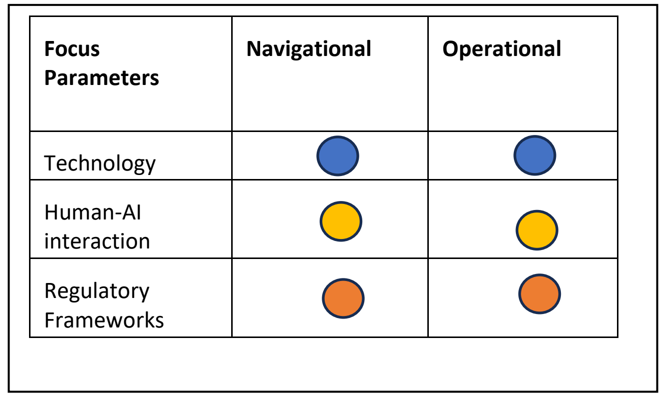

Figure 1:Framework for analyzing System, navigational and operational requirements of remotely controlled vessels.

This study draws upon a comprehensive review of the relevant literature, industry guidelines, and research and case studies as the main contribution. By gaining a deeper understanding of the navigational and operational requirements of remotely controlled navigation under the OOCs, maritime industry stakeholders can proactively address the challenges and capitalize on the opportunities under the same. The insights provided in this research study contribute to the advancement of safe, efficient, and responsible remotely controlled navigation for MASSs in the future.

With the advancements in modern technology, the maritime industry is shifting towards autonomous ships that should operate with varying levels of human intervention. Autonomous ships can have improved operational efficiency, reduce human errors, and enhance safety. However, that can introduce additional challenges, such as the trustworthiness of the same modern technology. Therefore, a comprehensive framework is required to define distinct levels of autonomy and ensure the responsible integration of autonomous technology into MASS operations. The International Maritime Organization (IMO) has provided some guidance by defining the levels of automation in MASSs, from degree 1 to degree 4, delineating the extent of human intervention required for autonomous vessels. (see Figure 2) (IMO 2018; Kim 2020). This allows for a gradual transition from traditional manned ships to increasingly autonomous ones while including OOCs in the spectrum.

This study focuses on **levels 2 and 3** of automation, as defined by the IMO. Degree 2 automation requires the presence of human operators onboard who can take control of the vessel at any time, whereas degree 3 automation allows unmanned operation with the ability to detect and react to situations requiring human intervention, both supported by OOCs. By focusing on these specific levels of automation, this study aimed to provide a comprehensive understanding of the navigational and operational requirements under the technology, human-machine interactions, and regulation perspectives necessary for the safe and efficient operation of MASSs.

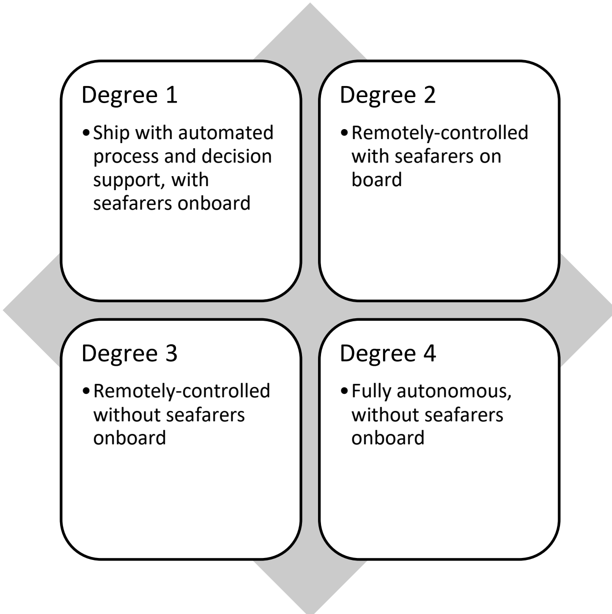

Figure 2: IMO MASS level of automation

Table 1. Requirements definitions

Terms	Definitions
Navigational requirement	Navigational requirements for remote control center-operated remote ships refer to the specifications and criteria that must be fulfilled to ensure safe and efficient navigation of ships remotely from a control center.
Operational requirement	Operational requirements for remote control center-operated remote ships refer to the specific criteria, conditions, and capabilities necessary to effectively operate and control ships remotely from a control center.

Regardless of MASS ship types, a standardized workflow is followed in ship operations to ensure effective functioning. This workflow comprises several stages: condition detection, condition analysis, action planning, and action control (see Figure 3: Generic ship function broken down to the sub-task level.) (DNV et al., 2018). These stages are crucial for proper ship navigation and operation and require the fulfillment of specific requirements in ship operation.

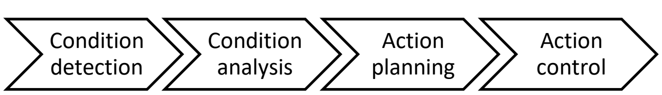

Figure 3: Generic ship function broken down to the sub-task level.

For instance, during the condition-detection stage, it is essential to gather information about the ship's surroundings, including geographic features, bathymetry, fixed and floating objects, and weather conditions. Additionally, the ship's condition, which may affect its maneuverability, must also be assessed.

In Degree-1 ships, the onboard crew typically performs operational and navigation tasks, often supported by automated decision support systems. However, in the case of Degree-2 and Degree-3 remotely controlled ships operating under OOCs, the same tasks must be carried out with a greater emphasis on reliable sensors for effective "condition detection."

Regarding "condition analysis," it is crucial to present information to remotely controlled operators in a manner that avoids information overload, ensuring their situational awareness is maintained. For Degree-2 and Degree-3 vessel operators to effectively analyze conditions, seamless communication with minimal latency between ships and OOCs is of utmost priority.

Concerning "action planning," it is necessary to establish more objective regulatory requirements based on the existing rules and regulations in ship navigation and operations, such as the International Regulations for Preventing Collisions at Sea (COLREG). Currently, these rules are subjective to a certain extent, requiring objectivity for remotely controlled operators to perform specific actions in particular ship navigation and operation situations. For instance, the initiation distance for maneuvers is not explicitly stated in the current COLREG, which leads to undefined range requirements based on human knowledge and experience.

In terms of "action control", this refers to the implementation of navigational and operational decisions that must be executed onboard vessels. The rudder and propulsion systems can execute ship steering and speed decisions in ocean-going vessels. Ensuring increased redundancy is crucial in "action control" mechanisms to handle extensive data for condition monitoring and mitigate risks associated with component or system failures. Requirements for the redundancy and maintenance of communication equipment play a vital role in ensuring effective remote-action control.

A comprehensive structure illustrating the envisioned communication flow between OOCs and present and future ships, as well as the interconnectivity with other shore-based infrastructures, such as ports and communication with fellow ships, is shown in Figure 4 (Autonomous Vessels, 2022). This diagram provides a visual representation of the intricate network through which actions and information are expected to be conveyed within the maritime domain.

The subsequent sections comprehensively delineate the navigational and operational requirements under the technology, human-machine interactions, and regulation perspectives about the four distinct MASS stages of ship function. These requirements were further categorized into two sets, providing more specific details and guidance.

Requirements encompass aspects of the ship's movement and navigation, whereas operational requirements encompass aspects of the ship's functionality and operations during each stage. The elucidation of these requirements aims to provide a detailed understanding of the specific criteria and considerations essential for each stage of ship function.

NAVIGATIONAL REQUIREMENTS

Safety of Navigation

The navigation system in RCC-operated vessels should ensure that the safety of their onboard systems, as well as the vessel's interaction with others (e.g., ship, environment, and sea conditions) are properly ensured following the required procedures, but not limited to the following (Autonomous Vessel, 2022; Article 2023; IACS 2023) :

Voyage Planning:

- Ability to plan and configure all aspects of the autonomous vessel's voyage, including navigation waypoints and machinery settings.

- Consider parameters such as speed, turning angle, wind speed,

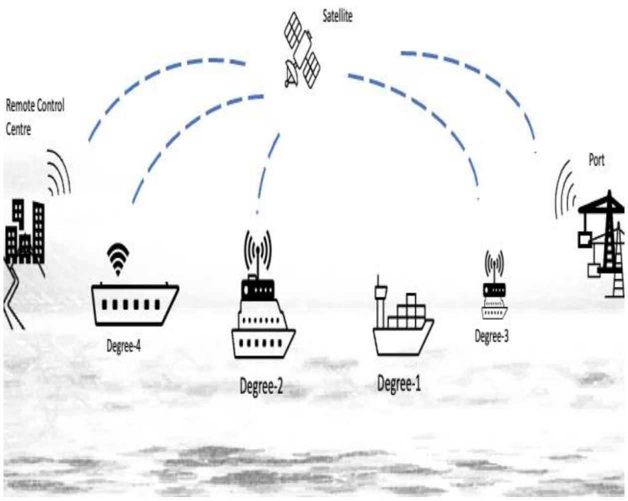

Figure 4: The framework for operating remotely controlled ships in an autonomous ship landscape.

and safety during navigation planning.

- Remote operators can refresh parameters as needed.

Progress Monitoring:

- Continuous monitoring of vessel progression throughout the voyage.

- Generation of alarms in the case of deviations from the planned route with adjustable tolerance levels based on navigation situations.

Situational Awareness and Communication:

- Maintenance of situational awareness to effectively respond to anomalous and emergency situations.

- Communication and information sharing with ports or coastal states, including coordination with Vessel Traffic Service (VTS) systems.

Adherence to the Convention on the International Regulations for Preventing Collisions at Sea (COLREG) principles.

- Continuous communication of intentions to surrounding vessels in accordance with the COLREG principles and local requirements.

- Reception and comprehension of communication from surrounding vessels.

- Monitoring environmental conditions and communication of navigational distress, if necessary.

Steering Capability and Safety

Maintenance of steering capability in the event of failure to ensure safe vessel operation.

- Avoidance of extreme weather conditions through navigation scheduling and continuous updates based on changing weather conditions.

Integration of weather data from ship-collected sensors and received weather data.

- Generation of the safest and most economical navigation route based on current and future weather estimations.

- Optimization of the navigation route continuously in response to weather conditions and maneuvering capability of the ship

By fulfilling these requirements, an autonomous navigation system can effectively perform voyage planning, progress monitoring, situational awareness, communication, and response to ensure the safe and efficient operation of the vessel.

Communication Systems

Establishing robust and reliable communication systems between remote control centers and remotely operated ships is crucial for effective operation. These systems enable real-time transmission of navigation instructions, sensor data, and situational awareness. Continuous communication between the vessel and shore control station is vital to ensure vessel supervision and safety management.

Requirements for Communication and System Restoration in Remotely operated Vessels

Communication Capabilities:

- Establish reliable communication channels with other vessels, pilots, harbor controls, and transportation teams.

- Enable communication between remote operators and external parties in fully autonomous and unmanned vessels by utilizing a remote operation center.

- Implement an automatic procedure for system restoration during emergencies, including sending signals to the remote operation center for assistance.

Communication Infrastructure:

- Utilize terrestrial communication bearers such as radio and mobile systems for ships operating in close proximity to the shore.

- Employ satellite communication for ships operating in the high seas.

- Ensure redundancy in communication equipment to maintain reliable communication availability.

Optimization of Transmission Capacity:

- Optimize the transmission capacity by reducing the amount of raw data transmitted.

- Parameters such as the field of view, resolution, color depth, and frame rate are adjusted to minimize data transmission.

- Apply preprocessing techniques, such as background subtraction, to reduce the volume of the transmitted information.

Post-processing and Augmented Situational Awareness

- Enable postprocessing of information and augmented situational awareness of operators.

- Conduct post-processing either at the operator's location or through cloud-based solutions.

By fulfilling these requirements, remotely controlled vessels can establish effective communication networks, ensure system resilience during emergencies, and optimize their transmission capacity for efficient and reliable operations.

Sensor Technology

Remote ships should be equipped with a range of sensors, such as radar, sonar, GPS, and cameras, to gather accurate and comprehensive data about the ship's surroundings, including other vessels, navigational hazards, and environmental conditions.

Requirements for Sensor Capabilities in Remote-Controlled Vessel Maneuverability:

Effective Detection of Navigational Risks: Sensors must accurately detect and identify various elements, including geography, bathymetry, fixed objects, floating objects, weather conditions, and ship conditions, which may impact vessel maneuverability.

Replication of Human Sensory Capabilities:

Sensors used in remote-controlled vessels should replicate the sensory capabilities of human navigators. These include the integration of several types of daylight cameras (stereo, multispectral, etc.), infrared (IR) cameras, light detection and range (LIDAR) cameras, and sound detectors.

Detection in Adverse Conditions:

Sensors must reliably detect objects posing navigational safety risks, even in challenging ambient conditions, such as heavy seas, darkness, fog, and inclement weather. Sensor technologies need to demonstrate robust performance under adverse weather conditions.

Redundancy for GPS Signal Loss:

The position of the vessel, relying heavily on GPS, is critical for safe operation. In the absence of an attending crew member, loss of the GPS signal becomes a critical issue. Therefore, alternative positioning methods must be implemented with redundancy to GPS or independent Global Navigation Satellite Systems (GNSs).

Reliable Navigation in Challenging Scenarios:

Robust navigation methods based on alternative technologies should be deployed to ensure reliable navigation under adverse conditions and GPS signal loss situations. These alternative technologies must demonstrate their ability to provide accurate and consistent positioning information.

By meeting these requirements, sensors in remote-controlled vessels can effectively contribute to maintaining navigational safety and maneuverability even under adverse conditions and GPS signal loss scenarios.

Control Systems

The remote-control center should have advanced control systems that allow operators to remotely control the ship's propulsion, steering, and other navigation-related functions. These systems should provide precise and responsive control over the vessels.

The control system should facilitate the following steps.

- The system can control the vessels and integrated apparatus, as per the design of the embedded system.
- The onshore or remote operator can take control of vessels at any time, and the system shall give high priority to the command of the remote operator.
- The system allows safe transitions between operating modes

Collision Avoidance Systems

Collision avoidance systems should be implemented to ensure the safety of remote ships. These systems can include automated detection and warning systems as well as the ability of operators to intervene and take appropriate action if necessary.

A prerequisite for a collision detection and avoidance system is the ability to execute a safe maneuver upon identifying a collision event. DNV (2018) outlined the stipulated requirements for RCC systems for collision avoidance (DNV et al., 2023).

- Enable RCC operators to make direct decisions based on situational awareness or evaluate algorithmic decisions in a decision-support context as necessary capabilities.
- Ensure effective presentation of condition analysis to remote navigators, meeting stringent requirements for decision-making clarity and accuracy.
- Recognize the distinct competence and skills required of remote navigators compared to traditional navigational officers, establishing specialized training and expertise requirements.
- Include quantitative requirements within existing COLREGs to regulate purely remote-controlled ships and accommodate increasing levels of autonomous action planning.
- Define clear range (i.e., objective) requirements for sensor systems to address the lack of explicit guidance in current COLREGs, establishing a requirement for precise distance initiation of maneuvers.

Redundancy and Fail-Safe Mechanisms

To mitigate these risks and maintain operational continuity, it is essential to implement redundant systems and fail-safe mechanisms. This entails the establishment of redundant communication links, backup power systems, and emergency protocols to effectively address potential system failures or unforeseen circumstances.

Redundancy can be achieved using either homogeneous or heterogeneous approaches. Homogeneous redundancy involves multiple sensors that measure the same quantity, whereas heterogeneous redundancy employs multiple sensors that measure different quantities. In heterogeneous redundancy, the failure of one sensor can be compensated for by calculating the quantity based on readings from the other sensors. Heterogeneous redundancy is considered more vital because it reduces reliance on the reliability of a specific sensor type.

In the event of an automatic system failure in collision avoidance, predefined safety procedures must be followed. This includes:

- Generating alarms to notify the remote operator and nearby vessels and notify nearby aid or rescue stations, ensuring prompt response and appropriate measures are taken.
- Redundancy to GPS (or independent GNSs).
- Redundancy in communication equipment

OPERATIONAL REQUIREMENTS

Communication and Control Systems

Reliable and robust communication systems are essential for maintaining continuous, real-time communication between control centers and remotely operated ships. This involves establishing secure and low-latency communication links to transmit commands, receive feedback, and monitor a ship's status.

The American Bureau of Shipping (ABS) suggests that all communication channels should be bidirectional, accurate, scalable, and supported by multiple systems, creating redundancy and minimizing risk (Autonomous Vessels, 2022).

The control center must have a well-designed and user-friendly interface that enables operators to control and navigate ships effectively remotely. The interface should provide access to various ship systems, such as propulsion, navigation, and sensors, allowing operators to monitor and adjust the parameters as needed.

Sensor Technology

Remote ships require a range of sensors to collect and transmit essential data to a control center. These may include video feeds, radar systems, sonar systems, and other relevant sensors to provide situational awareness and support decision-making during remote operations.

Sensors play a crucial role in assessing the propulsion and steering capabilities of a vessel and anticipating any potential changes. Sensor-based condition monitoring allows the assessment of critical components involved in maintaining these capabilities. It is essential to ensure the reliability of sensor signals throughout the operation.

In the absence of crew members available for sensor maintenance and repairs during operation, the robustness of these systems must be established, enabling maintenance and repairs to be conducted while the ship is in port. This can be achieved through either homogeneous redundancy, where multiple sensors measure the same quantity, or heterogeneous redundancy, where different sensors measure different quantities yet provide redundancy by compensating for the failure of one sensor through calculations based on readings from other sensors. Heterogeneous redundancy is particularly advantageous because it reduces the dependence on the reliability of a specific sensor type.

Overall, the implementation of sensor-based condition monitoring and redundancy strategies ensures the continuous and reliable operation of these critical systems in maritime settings.

Autonomy and Redundancy

It is imperative that remote-controlled ships are outfitted with sophisticated autonomous capabilities to facilitate self-navigation and maneuvering during the majority of their operations. Furthermore, the implementation of redundancy in critical components and systems is essential to ensure safe and reliable operation in the event of system failure or communication disruption.

In a report titled ‘Remote Controlled and Autonomous Ships’ (2018) (DNV et al., 2023), the redundancy requirements for ship components and systems were determined based on the level of risk associated with their failure. However, the shipping industry can enhance reliability and reduce the need for redundancies by adopting a condition-based maintenance approach, as observed in the aviation industry. This approach utilizes diagnostic and prognostic practices that rely heavily on data, thus necessitating a significant dataset to ensure reliability. The aviation industry benefits from standardized components and solutions, which enable access to large-scale datasets. In contrast, the shipping industry, which is characterized by equipment customization, faces limitations in acquiring such datasets. Therefore, successfully implementing condition-based maintenance principles in the shipping industry may require increased equipment standardization and broader adoption of integrated modules.

Moreover, future autonomous and remotely operated ships should prioritize adopting standardized equipment to enhance reliability and ensure redundancy. This will facilitate the accumulation of substantial data for error adjustment and continuous improvement, thereby improving overall system reliability. By leveraging standardized equipment and harnessing the power of data, reliance on redundancy can be minimized without compromising the system's performance.

Safety and Security

Comprehensive safety protocols and measures should be implemented to mitigate the risks associated with remote operations, including collision avoidance systems, emergency shutdown procedures, and cybersecurity measures to protect against unauthorized access and potential cyber threats.

According to (Tusher et al., 2022), navigational systems are the most vulnerable to cyber threats at the system level, whereas propulsion systems are the least susceptible element in future shipping operations. The Global Navigation Satellite System (GNSS), Electronic Chart Display and Information System (ECDIS), and communication devices on RCCs were identified as the three most vulnerable components at the subsystem level. Conversely, engine controls, RCC integration platforms, and cargo handling at ports were determined to be the least vulnerable subsystems.

Adopting a comprehensive set of measures to mitigate the risk of cyber threats in RCC is imperative. These measures should include the implementation of robust cyber security policies, conducting regular risk assessments, employing network segmentation strategies, enforcing strong authentication and access controls, ensuring regular software updates and patch management, establishing continuous monitoring and intrusion detection capabilities, providing user awareness and training programs; developing incident response and business continuity plans; fostering collaboration and information sharing; and adhering to industry standards and regulations. Additionally, it is crucial to have proper rules in place developed by organizations such as the International Maritime Organization (IMO), and to strictly follow guidelines provided by classification societies to mitigate the risks associated with cyber threats effectively.

Training and Certification

Proper training programs and certification processes should be in place to ensure that operators in remote-controlled centers are adequately trained and qualified to operate remote-controlled ships. Training should cover both technical aspects of ship control and emergency response procedures.

Remote operators play a crucial role in remote control and operator station operations, ensuring the safety of autonomous and/or remote-controlled activities. The International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) Convention currently sets specific requirements for vessel personnel's education, training, and experience. On the other hand, the International Safety Management (ISM) Code provides guidelines for ships' safe management and operation for onshore personnel and ship management.

According to (Saha, R. 2023), future remote operators must develop three key competencies:

- a comprehensive understanding of the system,

- proficiency in communication and technical knowledge and
- maritime competence.

In addition, knowledge of regulations, navigational skills, and engineering expertise were identified as necessary qualifications. The analysis suggests that extensive utilization of simulators for training and education, followed by a practical training period, can effectively prepare future remote operators. Initially, experienced Officers of the Watch (OOW) were preferred as prospective remote operators.

Further research and development of the required skills and competencies are necessary to facilitate the development of remote operators. Seafarers with many of the requisite skills and experience in ship operations will likely be the first remote operators. However, it is essential to identify gaps between current skill sets and the knowledge and skills required in the future. This will enable present seafarers to adapt to these and other emerging roles associated with autonomous and remote-control operations.

CONCLUSIONS

This study explores the maritime industry's navigational and operational requirements of remotely controlled navigation. By analyzing the specific criteria and considerations, to gained insights into the technological, regulatory, and human factors that shape the implementation of remotely controlled navigation systems. This study emphasizes the importance of standardized equipment to increase reliability and reduce redundancy requirements. By adopting standardized components and solutions, the maritime industry can leverage data-driven diagnostics and prognostics for improved condition monitoring and maintenance practices. This, in turn, enhances the reliability and performance of remotely controlled ships.

Furthermore, the study highlighted the need for seamless communication and minimal latency between the remote-control center and the ship. Adequate information flow and situational awareness are critical for remote operators to analyze conditions and make informed decisions. Additionally, implementing objective regulatory requirements, particularly concerning collision avoidance and sensor system range, is crucial for ensuring consistent and reliable navigational actions. The navigational requirements also emphasize the importance of safety, including the protection of onboard systems and interactions with other vessels and the environment. Proper voyage planning, adherence to regulations, and robust safety measures are essential for maintaining the safety of remotely controlled ships.

Overall, this study provides valuable insights into the maritime industry's navigational and operational requirements of remotely controlled navigation. This serves as a guide for stakeholders, regulators, and ship designers to navigate the challenges and opportunities associated with implementing remotely controlled navigation systems, ultimately promoting safe, efficient, and responsible practices in the industry.

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