Operational support framework for maritime autonomous surface ships under onshore operation centers

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ABSTRACT: In recent years, the concept of Maritime Autonomous Surface Ships (MASSs) has gotten attention both from the research community and shipping industry. The recent development in advanced sensing, communication, and control technologies makes it possible to operate such vessels remotely through onshore operation centers (OOCs). However, there are still several challenges that need to be addressed before such ships can be used safely and effectively in ocean environments. To handle these challenges faced by MASSs, a large-scale acceptance procedure from commercial industries and regulatory authorities, an on OOC framework is proposed in this research study. However, this study is limited to an OOC operational support framework for operational monitoring, guidance, and support. It shows how the proposed framework will support online MASS operations in ocean environments. This opens the ways to develop and operate the MASS concept through OOCs to control future vessels remotely by the crew sitting in onshore centers. It will enhance the MASSs technology acceptance both from the technological and regular regulatory perspectives. The study also identifies such challenges and their viable solutions in the aspect of operational support framework as well.

1 INTRODUCTION

Autonomous ships can introduce new and exciting technology concepts that could revolutionize the shipping industry. It is expected that there will be self-driving vessels that can navigate themselves without human input in the future. Autonomous ships can be operated by remotely or independently, depending on the availability of resources and infrastructure with respect to the desired level of autonomy. Autonomous ships can be programmed with many different goals for their missions, such as simply carrying cargo from port A to B, delivering medical supplies across dangerous territories, monitoring purposes, etc. Once such vessels have been programmed with mission goals, that can create internal maps in bridge systems, i.e. which ship routes such vessels should take (based on available information), as well as which operational conditions should execute (based on previous experiences). This allows future vessels to operate more efficiently than human operators because such vessels do not need pilot guidance through every route; instead, such vessels can rely on their autonomous navigation system (Li & Yuen (2022)).

Autonomous ships also got attention from multiple users ranging from commercial shipping companies, search and rescue operators, military units, for monitoring purposes, surveying, etc., with various reasons such as less operational cost in harsh sea weather, increase in safety requirements from policymakers. The shortage of human labor force in the shipping industry, etc. (Ziajka-Poznańska & Montewka (2021)) can also be considered as another reason. Advanced automation technologies such as IoT sensors, AI, data science, etc., enable autonomous marine system implementations much faster. Recent research and development activities show that autonomous ships will soon be available for commercial use on a large scale (Porathe (2014)), specifically for short sea shipping.

Different research and international organizations, such as the International Maritime Organization (IMO), Lloyd's Register, Bureau Veritas, Norwegian Forum for Autonomous Ships (NFAS), Rolls-Royce, and UK Marine Industries Alliance, define the level of autonomy based on different schemes in autonomous shipping according to their understanding (Kim et al. 2022). The International Maritime Organization (IMO) defines autonomy into four degrees, which are usually considered standards in the maritime domain, as described below (IMO (2018)).

- Level 1: Ships have advanced automation and decision support systems with onboard crew.
- Level 2: Remotely controlled ship with an onboard crew.
- Level 3: Remotely controlled ship without an onboard crew.
- Level 4: Fully autonomous ship

Other organizations, such as Rolls-Royce, Bureau Veritas, NFAS, and UK Marine Industries Alliance,

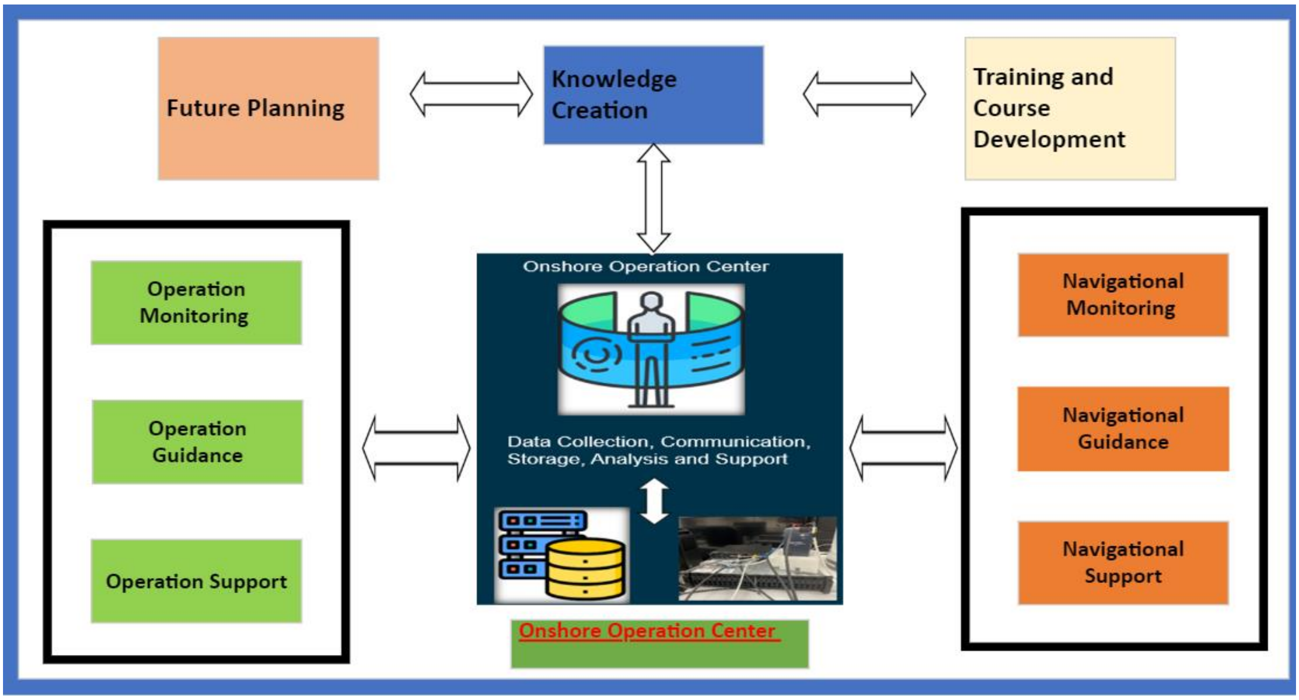

Figure 1. Onshore Operation Center Concept

also included the supplementary detailed classification levels of ship autonomy (Kim et al. 2022).

Adopting autonomous ship technologies will follow the steady shift step-by-step based on available technologies and their maturity level, starting from the lowest (level 1) towards the highest level (level 4). It is impossible to shift directly to a higher autonomy level (level 4: Fully Autonomous) without adequately evaluating the available technologies and systems, where various lessons to be learned. To ensure navigation safety, it is recommended to operate autonomous ships under the control or supervision of onshore operations centers (OOCs) at all levels of ship routes (Manno (2014)). The OOCs will play a key role in ensuring safe operations in autonomous shipping. Managing autonomous ships through OOCs will enhance the safety and trust of society and policymakers. It will shift the seafaring crew members' responsibilities from onboard ships to onshore office environments.

The rest of the paper is organized as Section 2, which will give an overview of the proposed OOC and its operational support framework concept; Section 3 will provide details about the operational support framework's major functions in terms of monitoring, guidance, and support, and Section 4 will conclude the overall study.

2 ONSHORE OPERATION CENTER DESIGN

The Arctic University of Norway (UiT) team is currently working on a OOC development project (uit.no/autoship), which will help the shipping industry's upcoming requirements for online operational support. The OOC is responsible for data collection, communication, storage, analysis, and support for operational and navigation aspects. The OOC also takes part and supports knowledge creation, and that knowledge can be used to support future ship navigators with course curricula. The course development will be utilized to train the maritime operation workforce to fulfill future market needs as per future technology. This center will also provide advanced training and knowledge to the shipping industry professionals for better resource management. The future industry will need these advanced OOCs for online operational support for shipping logistic operations based on autonomous navigation principles.

The current study introduces monitoring, guidance, and support functions for the operational aspect of future autonomous shipping. It discusses how the proposed framework for operation is linked with OOCs for data collection, communication, storage, analysis, and support, as shown in Fig. 1. The main goal of this study is to introduce a high-level overview of the OOCs in terms of operational perspective, specifically for autonomous shipping, as shown in Fig. 2. Operators in OOCs are divided into three groups based on their expertise and training: operation monitoring, guidance, and support groups. These operator divisions will help to manage the task more optimally than among operators who would overlook all diverse functions (like monitoring, guidance, and support) in OOCs. This study will address the following points in detail.

1) Operational support framework

Figure 2. Operational Support Framework for Autonomous Shipping

2) Why are these functions necessary for the shipping industry
3) The respective challenges
4) Some viable solutions

These autonomous ships are not only self-deriving vessels but also need other support functions from OOCs for safe operation guarantees.

3 OOC OPERATION FRAMEWORK

3.1 *Operation monitoring:*

Due to the absence of human crew onboard autonomous ships, vessel monitoring is crucial for safe operation in the sea environment. Operation monitoring is essential not only for ship navigation but also to create a safe sea environment. The operation monitoring process involves observing ship system operations, overlooking the respective environment, identifying navigation problems, and developing solutions. The purpose of monitoring is to provide services and collect information about ship system performance so that it can be used to make appropriate decisions, determine actions, and improve system performance. The OOC operators will observe autonomous ship operation remotely. This will help to identify navigation or operation issues and take corrective actions remotely as needed, just like the human crew onboard that performs the monitoring tasks.

In autonomous ships, monitoring can be performed automatically by using an advanced AI-based system. For some critical problems during ship operations, sometimes OOC operators need to watch the specific events or behaviors that occur over time and then record them for in-depth analysis. This type of monitoring usually provides more insight into what happened during a particular event or period of the problem. The automated monitoring systems make the OOC operator's job easier to manage because an operator only needs to look at warning messages generated by the systems, not into all historical data collected from different sensors to make conclusions. Automated monitoring systems use advanced technology such as IoT sensors, devices, and AI algorithms to understand the respective situations in systems automatically with greater precision without direct human involvement (Jacq et al. 2018).

If one is going to answer the question of ‘Why is operation monitoring important?’: The maritime industry is responsible for transporting roughly 80 % of all manufactured goods worldwide, making it one of the most important and large-scale industries (Kim et al. 2022). Unfortunately, some high-profile accidents with cargo ships have occurred due to a lack of monitoring and supervision, even from onboard ship operators (Cao et al. 2023). Operation monitoring is essential because it lets you know when any operational problems (like engine part failure, device failure, system response failure, etc) are happening and the root cause of those problems. Without monitoring the system downtime information, it seems impossible to fix the problem at an early stage. Operation monitoring also helps ship navigators avoid expensive mistakes by identifying issues early in stages (Yang et al. 2019).

Continuous ship monitoring will help to reduce the risk of accidents and system failures that may cause accidents. The operation monitoring systems will communicate online ship performance data to OOCs for analysis and to identify any technical issues related to the system that may arise. This way, the OOCs can gain the maximum efficiency of autonomous ships regarding operational utilization.

Overall, ship operation monitoring is essential to ensuring the vessel's safety and effective operation. This can help reduce the overall operation costs for ships (Veitch et al., 2022). Some of the operation monitoring challenges and solutions can be classified as: i) Safety and security issues, ii) System cost, iii) Monitoring the maintenance process, iv) Data availability issues, v) Limited visibility, and vi) Capacity limitation and communication delay.

Operation Monitoring Solutions :

Safety and Security Issues: The ship needs a monitoring system that can identify any problems in its operation, such as fire, flooding, or leaking oil. It also requires the installation of alarm systems to ensure the safety of the vessel, cargo, crew, other vessels, and onboard crew in the surrounding area of the ship. To manage the monitoring challenges, one solution to this problem is developing alarm systems based on intelligent sensors for monitoring each critical ship system (ABS (2016)). Ship structural monitoring is an essential aspect of ship safety. Autonomous ships should be equipped with structural monitoring systems such as hull health status, engine, generators, etc., which will help ensure the vessel, cargo, and crew safety.

Safety protocols and procedures are essential to protect the respective ship, cargo, and crew. High-resolution onboard cameras enhance the remote OOC operator capabilities to overview the issues in operating environments and ship systems. Such intelligent remote monitoring can help to identify and capture issues at the initial stages, allowing the OOC operators to control the situations in case of possible accidents

System Cost: Developing and maintaining a monitoring system that can work intelligently and automatically to monitor autonomous ship operations is costly because it demands much more sophisticated equipment, such as intelligent sensors and AI-based computing technologies. The cost of monitoring ship systems, manually can also be higher because it requires many people to work continuously. However, the accident ratio in manual monitoring can be higher and riskier, so it will eventually cost more in the end. Advanced manufacturing and digital technologies now significantly reduce the costs of developing advanced monitoring systems (Oikos-International(2017)). On the other hand, automatic monitoring works perfectly and generates alarms automatically to gain operators' attention for some corrective actions before possible accident situations. So, such systems will significantly eliminate human negligence factors by reducing possible future accidents.

Monitoring the Maintenance Process: Since every ship system must be maintained regularly, there is always an associated risk that some systems may have abnormal events during maintenance operations, which may cause a severe critical incident like loss of price cargo or loss of life at sea. Such maintenance can be done at ports with ship docks for vessel repairs. So, monitoring maintenance processes for better safety is essential. Computer vision techniques allow OOC operators to watch maintenance processes remotely and ensure it follows the standards and guidelines. Developing such systems can also be challenging in the maritime domain. Researchers have already applied IoT-based methods combined with a selected algorithm (i.e. YOLOv3) for vessel maintenance, design, and deployment monitoring to fulfill the demands of the IoTs-based ship managing scheme (Chen (2022)).

Data Availability Issue: Online data availability may also be challenging for these monitoring systems for better performance. While there are some sources of data available online (such as weather information), many other types of information (such as pollution levels and locally changing weather situations) can be accessed through third parties who have their proprietary systems. The solutions can be investing in advanced technologies and intelligent sensors to optimize the efficiency and performance of autonomous ships, including using IoTs, predictive analytics, and machine learning to minimize downtime and improve the efficiency of the ship's operation.

Limited Visibility: One of the significant challenges in operation monitoring is that vessels may be operating in ocean environments with limited visibility. For example, ships may be sailing in fog or other conditions that make it difficult for OOC operators to have adequate situation awareness. This can make difficult ship navigational situations due to the absence of physical crew onboard in autonomous ships. The OOC operators rely only on sensor information, and sensors may not provide correct or all data due to limited visibility of ship operating areas or communication challenges. A solution to this problem is investing in research and development activities to utilize advanced sensors and technology capable of overseeing such situations. It will also include developing intelligent solutions for autonomous ships, including new control and decision-making/supporting systems based on multiple sensors to overcome these limited visibility issues.

Capacity Limitation and Communication Delay: The other significant challenges in autonomous ships are limited data transfer capacity and communication delays with OOCs. Based on satellite communication for online data transfer from high-speed sensors (big data), another concern is the development of remote ship control systems. One solution to this big data problem is to send only features or essential information to OOCs for data processing and decision-making. Most initial data preprocessing can be done at local computing infrastructure to oversee the limited data transfer issue. As an example, OOCs can receive ship motion data as a substitute for camera images and replicate the operational condition at sea in virtual reality environments (Ota & Okazaki (2022)) based on the respective mathematical models. Communication delay can be managed by 5G and 6G technologies that allow faster communication with a much larger data transfer capacities. Developing and implementing advanced communication technology systems, such as satellite and wireless communication systems, will enable more efficient online monitoring and remote intervention in autonomous ships.

3.2 *Operation Guidance:*

Operation guidance is an integral part of OOC functions, as it allows OOC operators to remotely intervene with autonomous ships and provide oversight to ensure protected and efficient operations. The OOC operators can provide guidance in different scenarios, such as for maintenance of ship systems, technicians may need guidelines related to installed systems for maintenance purposes. Operational guidance is a crucial element in filling the gaps of the onboard human crew through OOCs. It will support autonomous systems in distinct phases of ship operations, like speed selection, direction, orientation, etc., for safe operation assurance (Gupta et al. 2022).

One option for guidance is to use the Automatic Identification System (AIS) in future ships. The AIS is a system that broadcasts information about ship positions and speeds at sea. It can inform other vessels about vessel locations, although it does not provide any control or command over vessels. The OOCs operators must know current vessel operating locations and sea environment conditions to keep safe autonomous ship operations. It can guide ships during the voyage planning phase for safe operations.

If one is going to answer the question of 'Why is operation guidance important?': Operation guidance in autonomous ships will enhance efficiency and safety and significantly reduce operating costs. Operation guidance will help optimize the ship's performance by providing feedback and recommendations to ship control systems to function safely and efficiently. Operation guidance can also provide additional flexibility and adaptability to the ship's operations. For example, if a vessel encounters unexpected obstacles or challenges, the OOC operator can provide additional guidance and assistance to help the vessel operate safely. Even some factors, such as route blockage or political situations, etc., cannot be modeled in autonomous navigation with enough accuracy, and these events must require guidance from OOCs to maintain safe and secure operations.

The AUVs can be used with GPS coordinates to help and guide them through treacherous waters without relying on more expensive equipment like radar systems or standard radio transmitters installed onboard vessels (Fan et al. 2022). Overall, operation guidance is an essential function of OOCs for autonomous shipping operations, as it grants remote guidance to ensure safe and efficient ship maneuvers.

Some of the operation guidance challenges and viable solutions can be categorized under the following sections i) Lack of trained human resources, ii) Cyber security issue, iii) System failure issue and iv) Human-machine friendly interface issue.

Operation Guidance Solutions :

Lack Of Trained Human Resources: Operation guidance faces the challenge of a lack of trained human resources, such as OOC operators, and how OOC operators will provide necessary supervision in case of system failure situations. No standard core curriculum exists to train OOC operators for autonomous shipping. There is a lack of research and development activities in this area to find the operational and functional requirements of autonomous ship systems. One solution is to invest in advanced training programs and find the required modification in existing teaching and research infrastructures. To continue the operation of the autonomous vessels and gain maximum performance efficiency, there is a need to dedicate the emergency maintenance staff ready to provide necessary and immediate support wherever required. In such events of system failures, the OOC operators may utilize AR or VR technology for guidance (Ota & Okazaki (2022)). Even during cargo loading and unloading stages, the OOC operators can provide guidelines to port operators or authorities if required.

Cyber Security Issue: How OOCs will provide guidance is another challenge in the event of cyber-attacks on autonomous ships. The challenge is that autonomous vessels face fast-growing exposure to cyber threats, uniquely due to fast-growing digitalization applications of the maritime sector, which places vessels and their onboard systems exposed to cyberattacks (Kanwal et aøl.2022). All system components must go through relevant cyber security standard tests before installation onboard. There is a need for robust and reliable communication systems to enable online monitoring and remote intervention and guidance in the case of cyber-attacks detected in ship systems. Such ship systems need continuous guidance from OOCs to avoid any fatal incidents due to cyber-attacks.

System Failure Issue: Another challenge is that some systems may not work well when encountering unexpected situations, such as malfunctioning equipment or obstacles in their path if a ship encounters a problem while operating autonomously. In that case, ship systems need enough guidance so that can decide how to handle it (e.g., by altering course or slowing down) without being overwhelmed by the situation itself—which could lead to near-miss or collision situation, i.e, If things go wrong too quickly or if there isn't enough time available for decision making (Zhao 2021). Developing and implementing practical algorithms and control systems to enable proper guidance are needed for autonomous ships to operate safely and efficiently.

Human-machine Friendly Interface Issue: To provide on-demand online guidance to autonomous systems with higher efficiency, human-machine user-friendly interfaces are needed between OOC operators and vessel systems. Without a friendly user interface, controlling multiple ships simultaneously by a single operator through an OOC seems impossible. This requires much more computing power than currently onboard ships, so developers must look for efficient solutions to improve their system performance and reduce costs by using existing hardware(Komianos (2018)). However, proper guidance from OOC operators is still required for optimized resource utilization and early recovery from system failures (Kurt & Aymelek(2022)).

3.3 *Operation Support*

Operation Support is the critical part of the OOC operation support framework for autonomous ships that coordinates and supports vessel operations. Operation support refers to the various systems and processes in place to ensure the smooth and efficient functioning of ship operations. This may include system maintenance, navigation and communication systems, i.e. system technologies, and processes essential for vessels to operate safely and effectively. The operation support framework can provide all mandatory support needed to operate autonomous ships. It will also ensure the optimality of the operational planning phase or actions suggested by autonomous systems both economically and safely (Abaei et al., 2022).

If one is going to answer the question of 'Why is operation support important?': Operation support is the most crucial element in operating autonomous ships through the proposed OOC framework for multiple reasons, such as keeping ships in appropriate operational modes, improved security, system failure handling, equipment functions failure identification and replacement, and other supports. Operation support can help with remote intervention, if necessary through OCCs.

Furthermore, support is needed and valuable to maintain the efficiency and effectiveness of autonomous systems during ship operations. Through the operation support functions in OOCs, ship operational efficiency can be gained by providing immediate support to vessel systems, if required. The absence of a trained human crew highlights the importance of operation support functions. Operational support is essential to deal with advanced systems handling in case of system failure occurs (Fan et al. 2022). It is one of the critical issues of autonomous vessel development programs to improve safety and security standards, which will also help in terms of society's acceptance of autonomous technology.

Without proper operation support functions, it seems impossible to coordinate autonomous system actions. If a ship is fully autonomous, it will perform its operations and does not need a crew. This means that no trained personnel are on board to perform these functions, which requires ship systems to assign qualified people who can provide adequate support for operating ships autonomously from OOCs (Utne et al. 2020).

Some of the operation support challenges and solutions can be categorized as: i) Maintenance support, ii) Lack of training facility, iii) Expensive supervision functions, iv) Maintenance challenge, v) Robust control system, vi) Required resource management challenge and vii) Integration of support system functions.

Operation Support Solutions :

Maintenance Support: One of the significant challenges of operation support in autonomous ships is ensuring safe vessel system operations as per defined criteria. Autonomous ships rely heavily on automation technology, which can be vulnerable to system failures or malfunctions. As a result, operation support and processes must be designed and implemented to detect and address potential system issues before they become severe situations, including backup systems and procedures to ensure continuous ship operations during system failure or other emergency circumstances.

One way to address such challenges is to design a robust Human-computer interaction system to provide continuous operational support. Advanced technologies, including AI, data science, intelligent sensors, and hardware devices, make implementing operation support functions more robust and accessible. The OOC operational support functions will ensure continuous ship operation and support during system response failures or other emergency situations (Murray & Perera (2020)).

Lack of Training Facility: There is a lack of training institutions and resources in terms of OOCs and autonomous vessel training requirements. This will create the required skill gaps for the maritime industry. The absence of crew members onboard may develop a lack of communication between OOC operators and autonomous vessels, leading to confusion or even mistakes during ship operations. Operators trained in traditional ship navigation must learn to communicate via OOC communication interfaces instead of being told what to do (Kooij et al. 2018). Updating the training course curriculum according to international standards is necessary to train OOC operators concerning operational support in future vessels.

Expensive Supervision Functions: Autonomous ships require continuous supervision by human operators through OOCs. This requires costly equipment, such as radar technology, that detects objects up to 10 kilometers from vessels. Vision and AI-based solutions can handle this challenge optimally rather than rely on expensive hardware solutions such as radar in some situations.

Maintenance Challenge: Maintenance in autonomous vessels is more challenging due to the absence of humans on board. Because autonomous ship systems are built using advanced technologies, they may need more up-to-date trained personnel for maintenance tasks than conventional ships. Another potential solution is to provide operation support teams with the necessary training and resources to maintain and repair such ships, effectively. This may include access to specialized tools and equipment, continuous training, and support to ensure that operation support teams are equipped and capable of successfully managing the maintenance and repairing tasks on autonomous ships. With in a selected time period, all operators of the operation support team need to refresh hands-on training courses based on modern technology to provide better operation supports.

Robust Control System: A robust controlling system interface is needed to make the operation support team's tasks more efficient and responsive. The control interface will provide online information such as vessel detection, tracking, state estimation, navigational trajectory prediction, and available control action functions on a single screen (Perera et al. 2012). Future ship systems should be equipped with enough robustness and trustworthy properties. OOC personnel should know and be trained to provide support in all critical situations that usually occur in harsh ocean environments.

Required Resource Management Challenge: Maintaining the required resources, such as power and spare parts, is challenging in autonomous ships. To keep autonomous vessel fleets operational, robust planning is required for arranging the power resources, such as refiling bunker oil and recharging batteries. Operating vessel fleets can be a challenging task without a proper operational support framework with OOCs. By utilizing automation and sensor technologies, it is possible to design robust human-machine interfaces by considering the human element in autonomous systems (Mallam et al. 2020). Therefore, considering autonomous vessels, a fully functional operational support frame is required.

Integration of Support System functions: The OOC functional support team must provide online support and the resources required to maintain continuous operations. The OOC system integrations need more effort to offer competent solutions for supervising and managing operation support teams. By implementing these solutions, OOCs can ensure vessel maneuvering is unharmed and efficient in future ships. Also, they can support continuous development and deployment of autonomous ships at a large scale.

4 CONCLUSION

To implement the autonomous ship concept into reality, OOC will play a crucial role in fulfilling the acceptance criteria from society and policymakers. The OOC will provide the monitoring capability to ship operations from land-based locations, where the domain experts analyze ship operations in online and take corrective actions for better performance management. Through the OOC systems, it is possible to detect or forecast the potential problems in ship operation. The OOC operators can interfere or take control of autonomous ships at any time if any problem forecast may lead to collision situations or dangerous situations for ship navigation. This study also enlists the challenges and their solution, including future work in terms of monitoring, guidance, and support in the aspects of the proposed OOC operation support framework.

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