Role of Onshore Operation Center & Operator in Remote-Controlled Autonomous Vessels Operations

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ABSTRACT

All industries, including the maritime sector, have recently utilized advanced technologies such as AI and data science based applications, such as autonomous navigation. The need for more skilled human resources and higher operational costs in conventional shipping will create the need for autonomous shipping. To implement autonomous shipping into reality, the shipping industry will create new demands for building supportive infrastructure & facilities to ensure the safe operations of such future vessels. The current study described the design an onshore operation center (OOC) with key elements and their significant functions as a supportive infrastructure for future vessel operations, where the role of the OOC and their operators in of autonomous vessels at all levels of autonomy, i.e., from onboard crew handling to fully autonomous. The OOC's primary goal is to provide necessary support functions in autonomous vessel operations. This paper discusses distinct levels of autonomous ships, the role of onshore operation centers, and remote operators from an operational support & control perspective. The current study also highlights the OOC design and its major functions, including the primary function performed by the OOC operators and their workflow, which is usually missing in the literature. A simulation-based case study is conducted, which demonstrates that operators may not make optimal decisions in complex navigation environments due to the limited available situation awareness (SA) system. The case study concluded that the OOC should provide SA-related support to the operators for better navigational safety.

KEYWORDS

Onshore Operation Center (OOC), OOC Operator, Remotely Controlled Vessels, Autonomous Vessels, Control System, Operator Action Loop, Operational Support, Navigational Support, and Situation Awareness.

1. INTRODUCTION

Autonomous transportation is already used in multiple commercial sectors, usually for land and air transport systems such as Uber taxi, Amazon Air delivery, Australia autonomous train, etc [1]. Maritime transportation systems still lag in utilizing autonomous navigation and operation technology. On the other hand, the maritime sector also faces severe problems of workforce shortage, and the lack of skilled personnel [2]. In the maritime industry, working hours are too long, and workers need to spend long durations away from the land due to the nature of their work. Such a working nature has reduced the interest of skilled people working in this sector. Autonomous technology can help to overcome the workforce shortage problem, by utilizing advanced automation technology, i.e. it is possible to automate the standard operational tasks where human operators are usually needed, such as navigation & mooring operations, etc [3]. Hence, the maritime industry can improve efficiency and create more efficient transportation solutions by implementing advanced digital technology as discussed previously [4].

The maritime sector is one of the most important transport sectors, covering roughly 90% of goods transportation [5]. In short-sea shipping (SSS), autonomous ships operating through OOC will be a suitable option due to the high operating costs linked with traditional ship operations, i.e., crew member costs, etc. Research results show that autonomous ship operations controlled through remote operations can reduce operational costs significantly, especially when an OOC operator is capable of managing a fleet of vessels [6]. Long duration in a sea environment is usually considered unsuitable for humans due to cold, wind, waves, and salt spray, which affects the human eyes, etc. Extended travel in the sea, e.g. for transportation and surveillance tasks, makes the job more undesirable for the onboard crew, which causes mental health fatigue and other health-related problems, including sea sickness [7]. Extended stays for tertiary area security and capturing potential hostile vessels can be much more dangerous tasks for the onboard military crew. These factors make unmanned ships more attractive for both commercial and military purposes [8].

Autonomous vessels have gained more significant attention in academic, research, and industrial sectors in the last few decades. Multiple research and development projects have been started to find the feasibility of autonomous vessels in terms of safe operations and cost-effectiveness in the current & future supply chain [9]. Another challenge is continuing maintenance activities in these autonomous vessels during their sea operation. The available AI applications and advanced sensor technology should support the development of autonomous shipping [10]. However, more effort in research and development (R&D) activities is required from an operational support perspective, such as managing ship condition monitoring and condition-based maintenance, etc [11].

Several autonomous ship projects have been developed to test and verify the concept over the last few decades. Especially Norway, China, Finland, and the USA have done substantial research work in the autonomous ship domain [12]. Several prototypes of autonomous vessels designed for research and civilian use purposes, i.e. fishing trawler-like vehicle ARTEMIS, the catamarans ACES and AutoCat, and the kayak SCOUT (Surface Craft for Oceanographic and Undersea Testing) [13][14]. These vessels can operate on automated navigation systems for their navigation. Furthermore, autonomous vessels are developed in several research studies in Europe, such as the autonomous catamaran Delfim, working by the DSOR lab of Lisbon IST-ISR [15]; the autonomous catamaran Charlie by CNR-ISSIA Genova (Italy) [16]; the autonomous catamaran Springer, industrialized by the University of Plymouth (UK), for finding contaminants [17].

The projects mentioned above utilize distinctive designs and methods for development based on their specific purpose utilization. Both industry and research communities are working on large-scale autonomous systems involving full-size vessel operations at sea. The level of vessel operations varies significantly from platform to platform, i.e., from remote control to fully autonomous prototype vessels. However, the maritime community and regulatory authorities raise multiple questions about the threats, safety & security, control levels, etc., of the autonomous and manned vessels operating in the same region [18].

It is observed from the literature and survey data around 71 % of accidents in the maritime sector involve human negligence factors [19]. Autonomous ship maneuvers based on sensors and advanced artificial intelligence (AI) algorithms can reduce the risk of accidents due to irrelevant human negligence factors [20]. This means autonomous vessels will have a better competency in terms of safe operation in the future than traditional manned ships. Confidently, autonomous technology can also help to reduce the number of accidents that can occur due to human negligence or navigation errors [21].

Curriculum design for OOC operator training is still challenging due to a lack of identified/required skills for training. Some initial levels of research studies are conducted to categorize the key competencies required for OOC operators, such as system understanding, communication, technical knowledge, and maritime competencies [22]. Still, there is a need for additional research and development activities concerning autonomous vessel operations as the critical competence required for future OOC operators. A significant knowledge gap exists between current and future skills due to technology variations, and auxiliary investigation studies are essential to finding actual competence in OOC operators of autonomous vessels [23]. Some available studies show that each remote operator will first require the skills and experience of a seafarer. However, OOC operators do not require the same navigation competence as conventional vessels in some situations. But OOC operators still need some general good seamanship skills like anchoring, ship drifting with winds & currents, and additional environmental circumstances knowledge & experience that can be utilized to maneuver vessels remotely [24]. Some of the required skills are identified in the auto-ship project and revealed in the Autonomous Ships document: Training Framework for Crew, Operators, and Designers document [25].

In recent decades, the maritime industry has shifted most of its manual operations into digital mode, which may help to quickly adopt and accept required autonomous technologies in the maritime sector, extensively [26][27]. However, before using it commercially, the maritime industries' trustworthiness in autonomous technology should be established, i.e., especially safety standards. Safety and security-related concerns are still challenging for autonomous vessels due to a lack of R&D in this domain. It is expected that the proposed OOC concept will solve most of the industry's concerns by providing online support & guidance to vessel operations, whenever essential through the OOC operators. Optimistically, the human-in-the-loop approach through OOC will solve most of the autonomous vessel safety and security-related concerns raised by the maritime industry and regulatory authorities.

2. LEVEL Of AUTONOMY IN SHIPPING

In the literature, the shipping definitions of autonomous navigation levels vary in a greater context. As a result, various organizations define autonomous navigation levels differently based on their perceptions [28] [29]. However, the majority still consider manual handling as an important level in the classification categories. An autonomous system means that the same entity can work without human inference; different researchers still categorized manned vessels in the classification levels, usually at level 0 or level 1 in most autonomous classification categories [29]. The International Maritime Organization (IMO) completed its scoping exercise regarding regulatory measures for Maritime Autonomous Surface Ships (MASS). It formed classifications for the degrees of autonomy, which are now somewhat recognized and accepted in the marine autonomy domain [30]. The autonomous vessels are classified into four distinct categories based on the operational functionality performed by such vessels, listed below and shown in Figure 1.

Level- 1: Seafarers on board to operate and control the vessels.

Level- 2: Remotely operated vessels with the onboard crews for supervision or emergency control.

Level-3: Remotely operated vessels without seafarers onboard.

Level-4: Fully autonomous vessels without human supervision.

In the level-1 system, the onboard operator handles the most operation-related functions of the vessel. The OOC will provide the necessary guidelines and support to the onboard crew if needed. No control functions are available for the level-1 vessels through the OOC control. At the autonomous level-2 system, the OOC operators will operate the vessels remotely. Still, onboard crew members are also available to operate and maintain the vessel, i.e., emergency control, hardware & communications failure situations, equipment malfunctions, etc. The onboard operator can take control of the ship whenever necessary. The autonomous system will generate alarm signals if any OOC control command failures. If such situations occur, the ship system will transfer vessel controls from the OOC to the onboard operator. The operator will supervise and monitor vessel operations, as required. In case of any navigation complexity, the onboard operator will communicate with the OOC operator for guidelines concerning their specific issues. In level-2, OOC will support the following functions: Supervised onboard crew regarding situations wherever needed, such as guidelines concerning the operational point of view and international maritime laws, etc, and operational support in vessel maintenance or failure, part replacement, etc, if required.

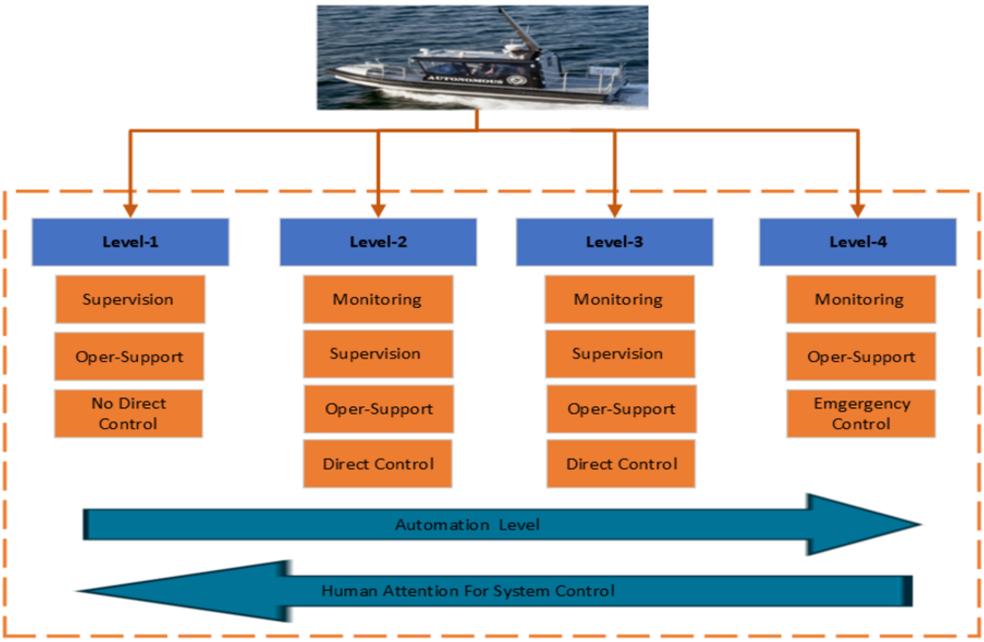


Figure 1. Functional Overview of OOC

The level-3 system works with advanced automation control capability and performs its functions as per pre-defined criteria. No onboard human crew is available to help and control the level-3 vessel. The autonomous vessels will connect with the OOC during their entire operation through a communication channel. At this level, there is no onboard crew member to operate the vessels; the remote operator will supervise the vessel's system remotely whenever needed. The OOC operators continuously monitor the vessel's operations remotely. Remote operators can take control of vessels whenever necessary, mainly if any abnormality occurs during operation, such as a system response failure situation, etc. The OOC operator will interact with the system's planning and decision process to ensure the optimization factor, such as navigational path planning, schedule, speed, etc. The remote operator needs to oversee and approve or modify system-generated plans based on factors like weather conditions or unavoidable situations in the operating area, such as war, path blockage, etc. The system will give higher priority to the command signal received from the remote operator than the autonomous system-generated command signal. The OOC remote operator can take control of the vessel at any time, whenever necessary, for safe operation assurance.

In level-4 system, vessels can operate without human intervention. In level-4, the role of OOC is to monitor and provide operational support in ship repair and maintenance phases. The OOC operator has limited interference with ship systems, such as emergency control capabilities. It is expected that many functions related to vessel operations will be handled by the intelligent systems without any inference from the human operators of the OOC. To reach this level-4, extensive research and development efforts are required. It is more feasible to rely on level-2 and level-3 for a many years to quantify the robustness of autonomous navigation systems. After the feasibility evaluations, i.e. in all complex navigation situations or operating environments, the shift towards fully autonomous vessels can be feasible, i.e. reliable, and robust.

3. ONSHORE OPERATION CENTER (OOC) OVERVIEW

Autonomous vessels still face many technical challenges regarding acceptance from society and regulatory authorities. Recently, the concept of OOC to support the operations of autonomous ships more effectively and securely has received considerable attention. The UiT Arctic University of Norway (uit.no/autoship) is working on the same concept of an OOC development project as shown in the Figure 2 to fulfill the shipping industry's needs and support their future autonomous vessel operations. The OOC concept may solve most of the safety-related concerns raised by the regulatory authorities by providing necessary support to operating vessels whenever required, i.e., help in emergency situations, & system failure situations, etc. This way, OOC will play a key role by providing the required infrastructure to enhance the safety of autonomous vessel operations. The OOC infrastructure must be designed carefully to support the autonomous vessel operations at all levels, i.e., level-1 to level-4. The OOC will be responsible for data collection, communication, analysis, and other support functions related to navigation and operation requirements. The OOC should also be equipped with advanced data analytics tools, which will be helpful for the operators in their planning and decision-making activities. The generated knowledge will be utilized for course curricula design to train future OOC operators. These OOC will provide advanced support and expertise to the shipping industry, which will be helpful in decision-making on optimized resource management, etc. The proposed OOC is equipped with the following essential functions:

- Operation Monitoring
- Operation Guidance
- Operation Support
- Navigation Monitoring
- Navigation Guidance
- Navigation Support

OOC will play a vital role at all levels (from level-1 to level-4) of autonomy in autonomous vessel operations. The OOC plays the role of the ship navigation system, with the difference that it is located onshore rather than onboard vessels. The OOC operator will play the same role as the onboard crew in monitoring, supervising, and providing operational and navigational support in autonomous vessel operations. The OOC operator will utilize the command-based controller for the ship's operations. The commands from remote operators will have a high priority compared to autonomous system-generated decisions. OOC is an essential part of these advanced next-generation maritime systems to provide the necessary support for their operations, especially in complex situations such as harsh weather, emergencies, system response failure, narrow passages, operational and navigational support, guidelines, etc.

The functional overview of the OOC shows that it will support autonomous vessel operations at all levels of autonomy, as shown in Figure 1. Autonomous ships will be controlled by the remote OOC operators working onshore, whose jobs might diverge from monitoring & supervision to remote control. The main goal of OOC is to facilitate remote operations of autonomous vessels in a well-organized, protected, and safe way in all scenarios. The idea can be expanded to support autonomous fleets through OOC in the future. The proposed automatic alarm scheme will inform or alert remote operators in OOC if any pre-defined variation occurs during vessel regular operations, e.g. planned path deviations, speed variations, or abnormality in onboard sensors or control systems.

3.1. Major Elements of Onshore Operation Center

Figure 2 shows an overview of the OOC environment and comprises three significant elements, which are described and listed below consecutively.

3.1.1. Information Display

The field of augmented reality (AR) is presently undergoing significant advancement as a possible information display method. According to the definition in [31], AR is characterized by three main features: integrating the real world, real-time interaction, and accurate 3D registration of real objects. It has the potential to change human perception of the real-world environment profoundly. Information display is a crucial element in AR systems, with head-mounted displays typically being the primary choice. These displays are frequently utilized in developing remotely operated land vehicles [32,33,34] and vessels [35]. However, there are still some issues that remain to be solved with head-mounted displays, such as limitations of environment lighting on optical see-through head-mounted displays [36] and eye fatigue [37]. Since vessel maneuvering is considerably more complex than land vehicles, requiring substantial teamwork and cooperation, often extending over longer durations, large flat and curved screens are used as the display in the proposed OOC design.

Implementing large flat and curved screens can enhance several visual factors, such as field of view, depth perception, and natural viewing angles. The critical information related to vessels, such as engine power system status, health conditions of mechanical parts, planned ship route, environment conditions, possible collision risk, vessel locations, vessel speed, emission levels, etc, needs to be transferred to OOC and displayed on large screen continuously for safe operation monitoring, support, and guidance purposes. The advanced IoT systems make it easier to share this information with remote OOCs. The large screen displayed information that will enable the remote operator to make optimal decisions concerning safe operations of these autonomous vessels.

The large amount of information that will be collected from the IoT devices make it another challenge for the user-interface design of OOC. The OOC user interface must be designed carefully, with the information of all relevant stakeholders, to decide which data needs to be displayed on large screens for continuous monitoring purposes, etc. This area still needs more research & development activities to identify the critical information required for continuous monitoring related to vessel operations . Another challenge that OOC operators might face is an information overflow problem, which may occur not only in autonomous vessels; manned vessels may also have similar situations. Undoubtedly, the

OOC operators will be more overloaded with such information from autonomous vessels compared to manned ships [38]. The absence of a visual aspect of the operating environment in autonomous ships can be compensated by installing different IoT, which may cause the information overflow problem in some situations.

During the OOC design phase, it must be ensured that remote operators will receive all required information, at least as onboard navigators, during regular operations. The information related to operating environments, such as wave spectrum information, including vessel motions including slamming, rolling, and pitching motions information can be useful in some situations [39]. Only necessary information will be displayed on the OOC operator screen to avoid the information overflow problem. Hence, an appropriate human-machine interface needs to be designed to reduce information overload and to avoid any operator confusion. One solution to this problem is to reserve a specific area in the

Figure 2. Onshore Operation Center Design

curved screen for vessels with critical risks. An alarm system should be developed based on the critical situation order, as shown in Figure 3. The proposed alarm signals can be further classified into three types: red, yellow, and green, based on their critical situation order, as shown in Figure 3. The red alarm signal needs more attention from the OOC operator than the yellow and green alarm signals. The operator action plan scheme design will enhance the working efficiency of OOC operators. The design of such functions for managing a critical risk vessel situation still needs to be investigated further. The action plan should be designed based on the domain expert’s recommendations. The operators can only focus on those vessels that need urgent support or guidance based on the priority of critical situations, such as red alarm situations first, then yellow and green alarm situations consecutively. The priority queue scheme will substantially reduce the operator’s workload and optimize their work routine. It will be easy for operators to work on the most critical

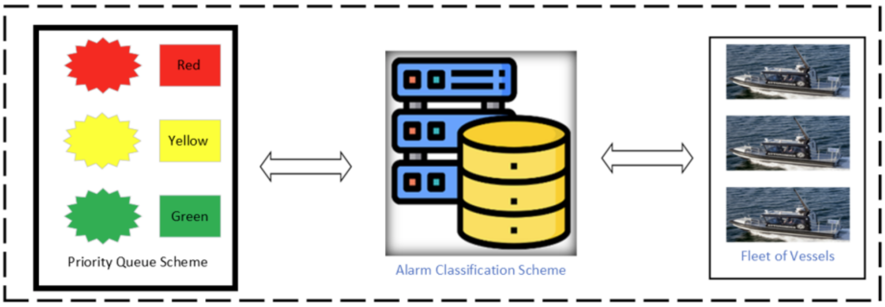


Figure 3. OOC Operator Action Plan

situations first based on the priority order shown in the reserved area.

3.1.2. Critical Monitoring

On additional screens, the operator can check the detailed information about the critical vessels before taking actions or providing guidelines depending upon the vessel’s autonomy level. Such screens can provide OOC operators additional required information. Such detailed information can help OOC operators a better solution for vessel navigators during ship operation. The priority order of the alarms concerning emergency situations will be significantly helpful for remote operators to focus on the most critical situations first. It will also assist in solving the information overloading problem for the OOC operators.

3.1.3. Control Objects (Control Chair, Joystick, Control Equipment, AR, VR, Communication Devices, etc.)

The OOC environment must be designed carefully to support the respective operators. The OOC design can be as close to an ship bridge environment as possible so that the OOC operators can feel like navigating a vessel. The control chair will make it easy to get an overview of the overall OOC operational environment, such as monitoring, and remote-control functions. The OOC can also be equipped with a joystick for control functions of vessels with an appropriate user interface. It may also be fitted with AR and VR-like equipment for more appropriate control during ship handling and monitoring.

4. ROLE Of OPERATOR IN OOC

The onshore operation center teams can comprise of ship operators, supervisors, captains, marine engineers, IT engineers, etc. The ship operators are the backbone of the OOC; other people are specialized experts in their respective domains who will provide the operator's help, supervision, and guidelines as requested. Some frequent questions about remote operator capabilities include how many ships one OOC operator can manage simultaneously. It is possible that one operator can control multiple ships at a time, however that may depend on the respective navigation situation. The concept behind the development of OOC is to operate a fleet of vessels by each operator. Additional research and development activities are required to identify an appropriate number of ships that each operator can control in various situations. Most probably, with matured technology with system intelligence, the number of vessels handled by each operator can increase simultaneously. However, multiple ship management at a time may be an issue for OOC operators in the early starting stage due to the need for more experience and system testing in all circumstances.

When the system reaches its matured level, one operator may manage multiple ships simultaneously. To achieve the operator goal of several ships simultaneously handling, one key factor that affects the most is the intelligent operational scheduling of these vessels. All vessels handled by each operator should not reach critical situations simultaneously, such as port entry and exit, narrow passages, high traffic areas, cargo handling, loading and unloading phase, etc., because the vessel needs more attention from the OOC operator during these critical situations due to the severe accident risks involved.

The OOC can play a vital role in monitoring and controlling the future autonomous feet of vessels, specifically in the steps of port entry and leaving. Due to the lack of supportive infrastructure for the autonomous vessels in port handling stations, remote operators may need localized communication connection with the port operators in some situations. This will make the autonomous system integration more accessible and reliable to avoid accidents. Port entry and leaving time are the most crucial operation segments and most accidents occur during this period due to multiple factors such as high traffic, narrow pages, etc. The role of a remote OOC operator is also fundamental in monitoring the structural health of the vessel and the cargo loading and unloading phase of goods from the vessel as well.

The role of the operator is crucial in these states.

- Entry into the port terminal (a lot of vessels are waiting for a schedule or signal from the port entry operator)
- Cargo handling phase
- Maintenance phase
- Leaving the port
- Narrow passages area or linked canals
- High-traffic zone
- Check the power and emergency backup resources before the port leaves.
- Check the health status of engine parts.
- Based on the weather forecast, update the navigation plan of vessels.
- Communicate with the local authority regarding the needs of the vessels.

4.1. Operator Working Scheme

The OOC operators are responsible for operating autonomous vessels safely. However, OOC supervisors can monitor the overall OOC operations and assist operators in handling and complex navigation situations. The operator and supervisor must have the relevant knowledge, skills, and experience to efficient ship operations. Ship navigation knowledge is required for the OOC operators. According to implemented maritime laws, OOC operators must be familiar with vessel inspection requirements, such as safety certificates and machinery health assessments, to maintain the vessel's suitability for operation. OOC operators must deliver support whenever it is essential.

The OOC operators are divided into two groups in the proposed operator working scheme: operational and navigational [40][41][42], as shown in Figure 2. The idea behind the division is to handle the tasks more effectively based on crew competence and expertise. The operator functions can be further divided into monitoring, guidance, and support tasks, as shown in Figure 2.

4.2. Key Task Perform by Operator

The OOC operator can perform the following tasks related to autonomous vessel operations listed below. Figure 1 provides the overview of the tasks performed by the OOC operators in all levels of autonomous shipping, including level-1, level-2, level-3 and level-4.

1. Monitoring

The OOC operators can monitor the operational and navigational aspects of autonomous ships. Monitoring the vessel's operation during its journey is essential for a safe operation guarantee. Continuous monitoring ensures safe operation during the sea journey and provides the necessary guidelines and support to autonomous vessels whenever required, depending upon the vessel's autonomy level.

2. Supervision

The operator can supervise the onboard crew and control system in level-1, level-2, level-3, and level-4 of the autonomous ship whenever necessary. Especially in the early trial of level-2 and level-3 of autonomous vessels, both onboard crew and system need continuous supervision from the OOC operator regarding the operational aspect of the vessel. The control system needs supervision from the remote OOC operators until the autonomous vessel system reaches its defined robustness level, which will take time to achieve this maturity level.

3. Intervention

Operators can intervene with autonomous systems at any time for safe operation handling. The priority of the operator command signal should always be higher than the autonomous control system. During the planning phase, remote OOCs must monitor and sometimes interfere with a planning phase for optimization purposes depending upon the level of autonomy due to multiple factors that are challenging to model or adopt in an autonomous system, such as weather conditions, accidents in the planned path, war zones, etc.

4. Direct control

Appropriate navigation tools should be considered in the OOC platforms to enhance operator performance. For instance, advanced ship predictors can provide trajectory predictions at both local and global scales [43][44], are essential for navigation safety. Additionally, related tools designed for path planning [45] and cost analysis [46] can be employed to design optimal sea routes and minimize operational costs. As the OOC is designed to handle and analyze large volumes of navigation data, it is feasible to utilize newly developed AI-driven tools such as advanced predictors and optimized voyage planning, etc., based on big data. The OOC operator can take control of the vessel if the autonomous system fails to handle disaster situations, such as response failure situations, sensor malfunction, etc.

4.3. Operator Action Loop

Operation monitoring is a critical element of the OOC operator's job during the entire journey of the autonomous vessel operation, regardless of their autonomy levels. As the first step, any alarm or event will require more attention and monitoring from the remote OOC operator. Based on the pre-defined rules, the operator will monitor the event closely and wait for the system to configure the solution itself with a pre-defined time threshold. If the system reconfigures itself, the event will go to the end state. Otherwise, the operator will analyze the event based on the available data and try to find a possible solution. During this process, it is recommended that the group supervisor be in the loop if the event belongs to a critical class. Involving their supervisors will help them find the best and most optimized action to solve this particular event or problem. The operator will trigger the action based on their decision and discussion with the supervisor. After triggering the action, if the problem is solved, the event will go to the end state; otherwise, it will go to the loop again until the problem is solved. The OOC operator will follow the decision loop to ensure the safe operation, as shown in Figure 4.

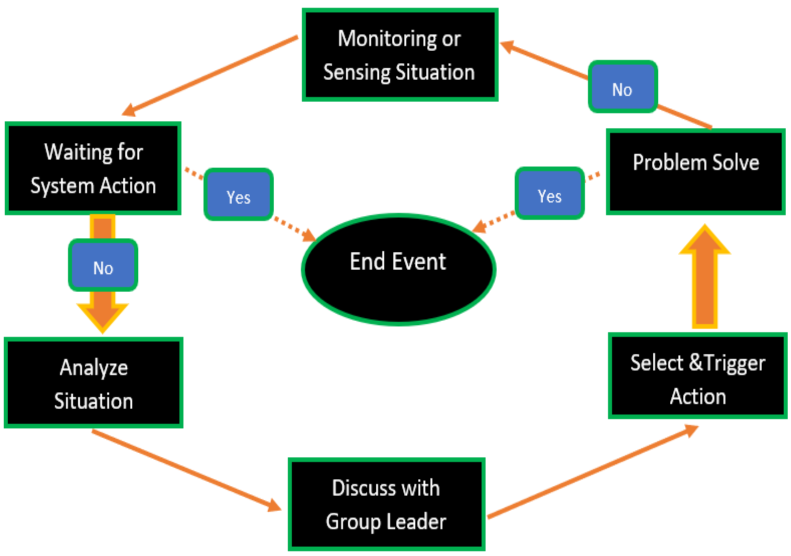


Figure 4. OOC Operator Decision Loop

5. CASE STUDY

In contrast to conventional navigation, vessel maneuvering in an onshore location, such as the designed OOC (Figure 2) in this paper, can introduce potential challenges as discussed before. Numerous factors must be carefully considered in such vessel navigation conditions, including the availability of navigation datasets, transmission security of the data, reliability of remote control systems, limited vision of OOC operators, etc. Therefore, decisions made by OOC operators may diverge from those made in conventional navigation due to the difference in understanding the respective SA in the OOC. This paper presents a case study that emphasizes the factors mentioned above when maneuvering a ship in the designed OOC. As depicted in Figure 2, the visual data displayed on the screens serves as an important resource for maintaining SA. It is thus reasonable to assume that the acquisition of this visual data is impeded by system or transmission errors. The objective of the case study is to investigate how decision-making varies under different conditions of SA acquisition in the OOC. The findings can provide feedback for the OOC design so that the related functionalities can be optimized.

5.1 Situation Awareness in the Complex Environment

SA is a critical concept in maritime safety. It is formally defined in three steps[47]: 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 shortly. In modern navigation, ship bridges are equipped with various advanced electronic equipment, including GNSS systems, gyroscopes, radars, AIS receivers, etc. However, the view from the navigator's eyes still plays a fundamental role in observing the respective environment. Rule 5 of COLREGs explicitly mandates that "every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions to make a full appraisal of the navigation situation and the associated risk of collision" [48]. In conventional shipping, the view from navigators' eyes is mainly from the ship bridges where the rudder and propulsion control systems are located (also known as first-person perspective). In addition, shipboard ARPA/radar systems offer navigators a comprehensive global perspective, and this global perspective is indispensable when first-person perspective information is limited, such as during navigation at night or in harsh weather conditions. It is worth noting some highly skilled navigators can share similarities in understanding situational awareness in some ship navigation situations. Consequently, decisions made by onboard navigators benefit significantly from both first-person and global perspective information sources.

As for power-driven vessels, which are applicable in most ship encounter scenarios, the COLREGs include distinct regulations for three general encounter situations: overtaking (Rule 13), head-on (Rule 14), and crossing (Rule 15). Furthermore, Rules 16 to 19 also incorporate regulations that promote proactive measures to reduce collision risk. However, it is essential to note that these three general encounter situations only address scenarios involving two ships. With the introduction of remotely-controlled and autonomous ships, the encounter situation among different types of ships can become more complicated [49]. Therefore, it is recommended that the maneuvering strategies remain adaptable and responsive to the evolving circumstances [50].

In the design of the OOC, large screens are incorporated to display view information captured by onboard equipment. While these screens can offer operators first-person perspectives of the navigation situation, it is essential to recognize that this view is purely an indirect representation of the bridge view. In more challenging scenarios, image transmission may experience considerable time delays, and that can affect the information displays. Additionally, in adverse weather conditions, the image quality captured by onboard sensors can deteriorate and that can also introduce additional challenges in remote navigation. With diverse sources and types of navigation information, operators in the OOC may have different decisions regarding the same ship encounter situation. For navigation safety, it is thus informative to explore the diversity of decisions made by OOC operators provided with different sources and types of information. For example, decisions regarding navigation through high-traffic waters may differ depending on whether the OOC operators have clear visibility or rely solely on radar.

5.2 Simulation experiment preparation

As remotely operated vessels are still in the developmental phase, there is a shortage of sea-trial experiments and research studies in this field. Therefore, a simulation experiment is designed and conducted to assess how OOC operators respond to complex ship encounter situations. The UiT bridge simulator serves as the OOC working platform in this experiment. The bridge simulator has a panoramic curve scene and control modules inside (see Figure 5). As stated before, the OOC should have a similar view and control units. A ship's steering on the bridge can be viewed as a scenario in which the ship has no crew members onboard but is remotely operated.

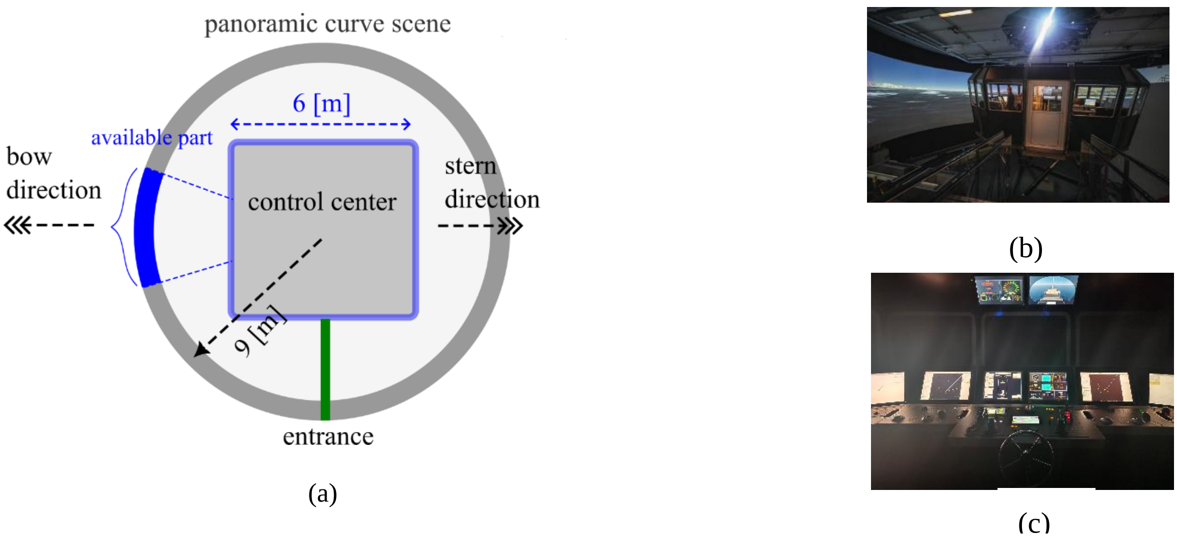


Figure 5. The cross-section of the UiT bridge simulator (a); Simulator appearance from outside (b); Detail of the control center (c)

A complex ship encounter scenario is created within the simulator (Figure 6). This scenario involves seven ships sharing the same maritime area, with their initial conditions detailed in Table 1. The operator's task is to navigate the own ship (OS) safely through this area. Meanwhile, OOC operators are encouraged to consider minor course adjustments, as making significant changes in the course may lead to speed reduction, which is less economically efficient.

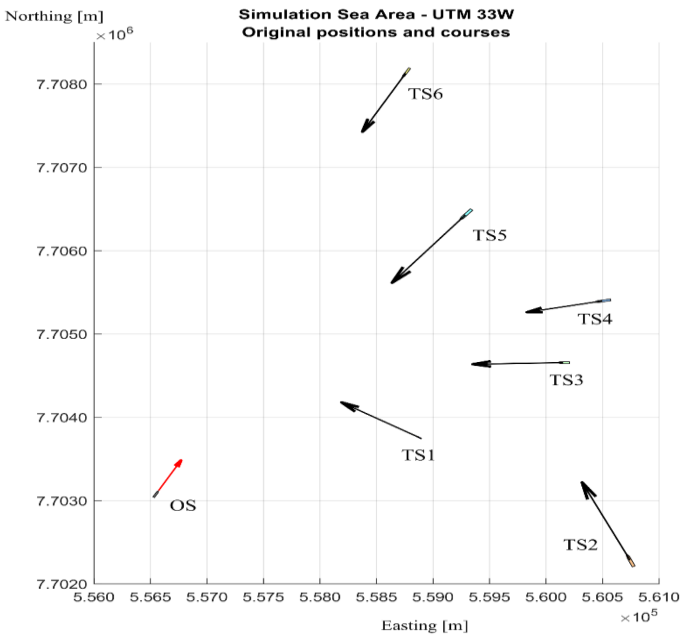


Figure 6. Ship encounter scenario for simulation experiment. The plot is based on the UTM coordinate (33W).

Table 1. Original states of the ships

Ship label	SOG [kn]	Course [deg]	Distance to OS at the beginning [km]	Ship size (length/beam) [m]
OS	10	35	-	90/16
TS1	10	303	2.387	55/9
TS2	12.8	337	4.254	165/27
TS3	10	270	3.895	110/21
TS4	8.5	260	4.538	149/23
TS5	13	220	4.166	170/27.5
TS6	10	210	5.144	141.7/18.9

Two operators (A & B) with experienced navigation expertise are invited to maneuver the OS in the designed scenario separately (Case 1 & 2). Case 1 is designed so that Operator A can only obtain the nearby ship information provided by the APRA (see Figure 7). In Case 2, Operator B has access to view data from both the ARPA system and a camera. However, the camera's view is limited to a small portion of the panoramic curve scene and has a restricted angle, covering only the OS's beam (see Figure 5(a) and Figure 8).

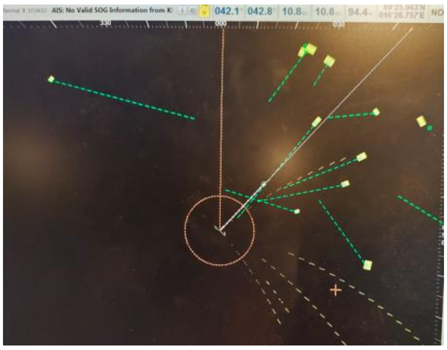


Figure 7. APRA system in the control center. Operator A only has access to this information in Case 1

Figure 8. APRA system and the limited section of the panoramic scene. These two sources of information are provided to Operator B in Case 2.

5.3 Experiment Results

In Case 1, Operator A soon realizes the collision risk with target ship 1 (TS1). Instead of making a starboard turn, Operator A reduces the speed and lets TS1 pass first. Meanwhile, Operator A also detects that there is another threat from TS5 ahead; a minor change of course to the port side is thus executed (see Figure 9(a) and 9(b)). However, although these decisions allow OS to avoid conflicts with TS1 and TS5, Operator A does not realize proactively that these decisions increase the risk of OS colliding with TS3 (see Figure 9(c)). After realizing TS3 is coming from the starboard side, Operator A neutralizes the rudder and accelerates. While a collision is successfully prevented, the proximity between the two ships indicates a high-risk situation (see Figure 9(d)). This is particularly concerning for OS, as its starboard is exposed to TS3's route, increasing the risk of capsizing in the event of a collision.

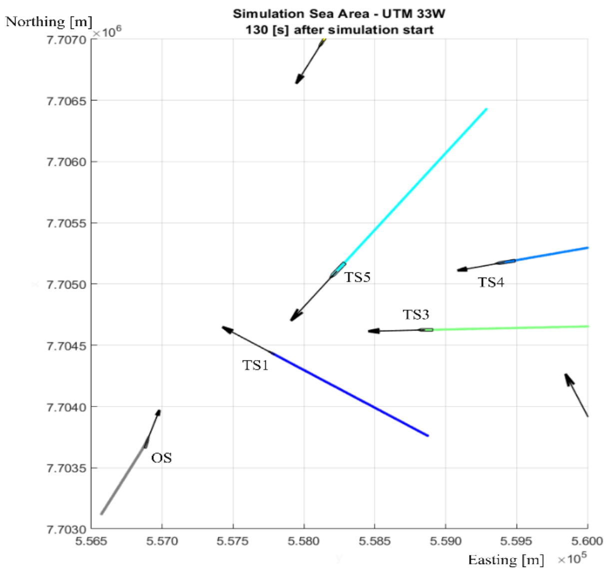


Figure 9(a)

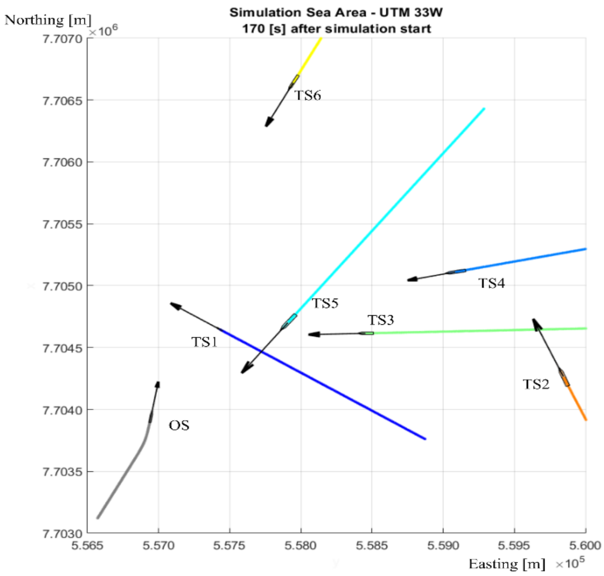


Figure 9(b)

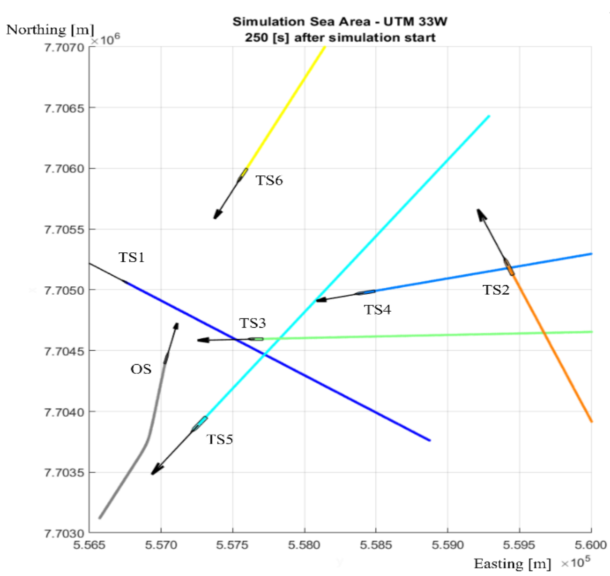


Figure 9(c)

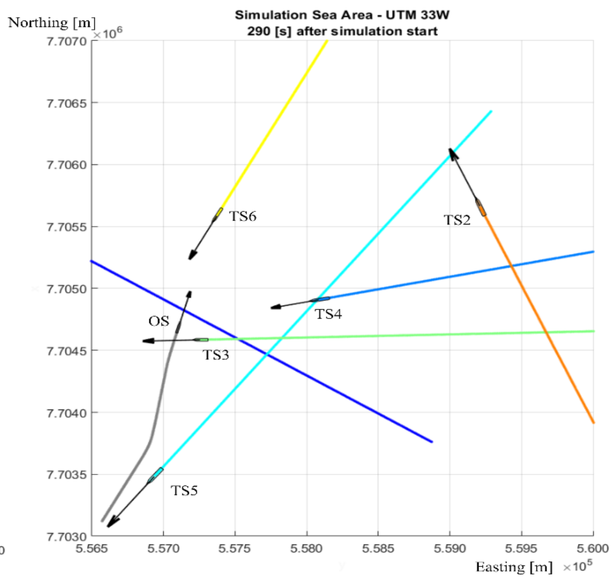
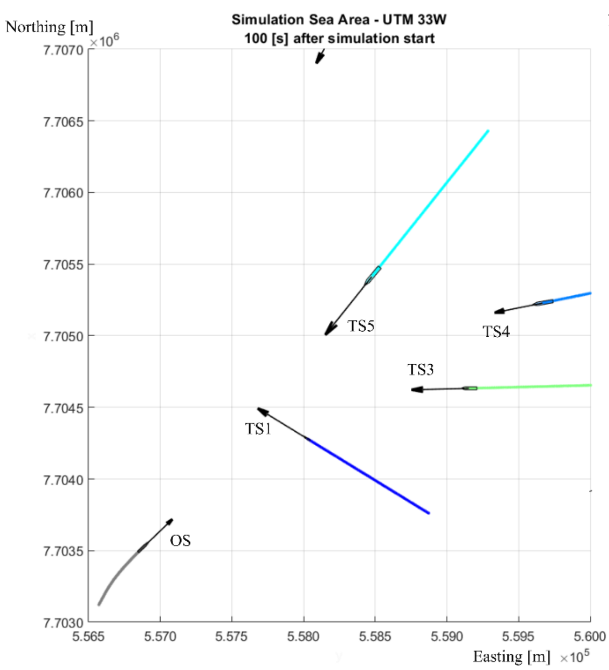


Figure 9(d)

Figure 9. Case 1 (Maneuver by Operator A with only view information from APRA)

In Case 2, Operator B notices a significant difference in the view information compared to conventional shipping. As a result, more cautious maneuvering is taken. After recognizing the collision risk with TS1, Operator B reduces the vessel's speed and makes a major change of course to the starboard side (see Figure 10(a)). This decision allows OS to safely pass TS1. However, as TS3 approaches directly in front of the OS (see Figure 10(b)), despite the ARPA providing an excellent global perspective, the limited range of the first-person view makes it challenging for the operator to confirm whether the OS can safely navigate past TS3 (see Figure 10(c) and (d)). It is approved by Operator B that if a full bridge view were available, overseeing such encounter situations would be easier.



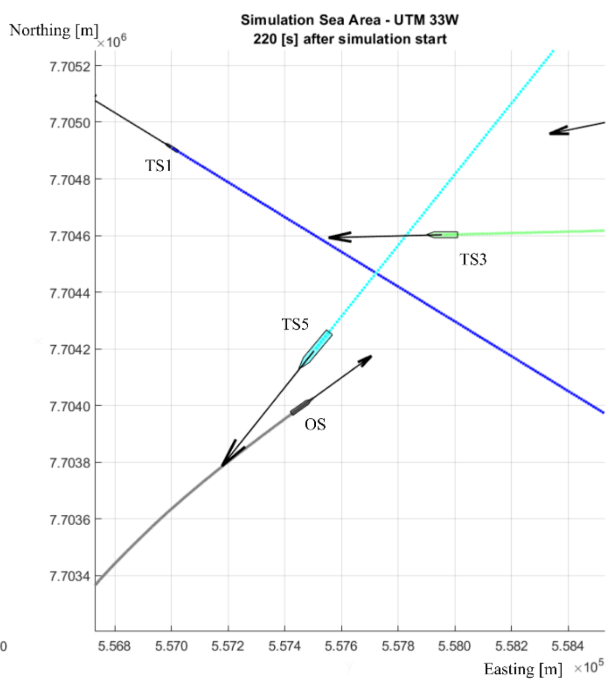


Figure 10(a)

Figure 10(b)

Figure 10(c)

Figure 10(d)

Figure 10. Case 2 (Maneuver by Operator B with view information from both APRA and limited camera)

When comparing the maneuvering trajectories of these two operators within 800 seconds after the start (see Figure 11), it is clear that the change of course in Case 2 is quite substantial. While the maneuvering of Operator B in Case 2 has no obvious moments of danger, it is still worth noting that there is a loss of time and possible increased fuel consumption.

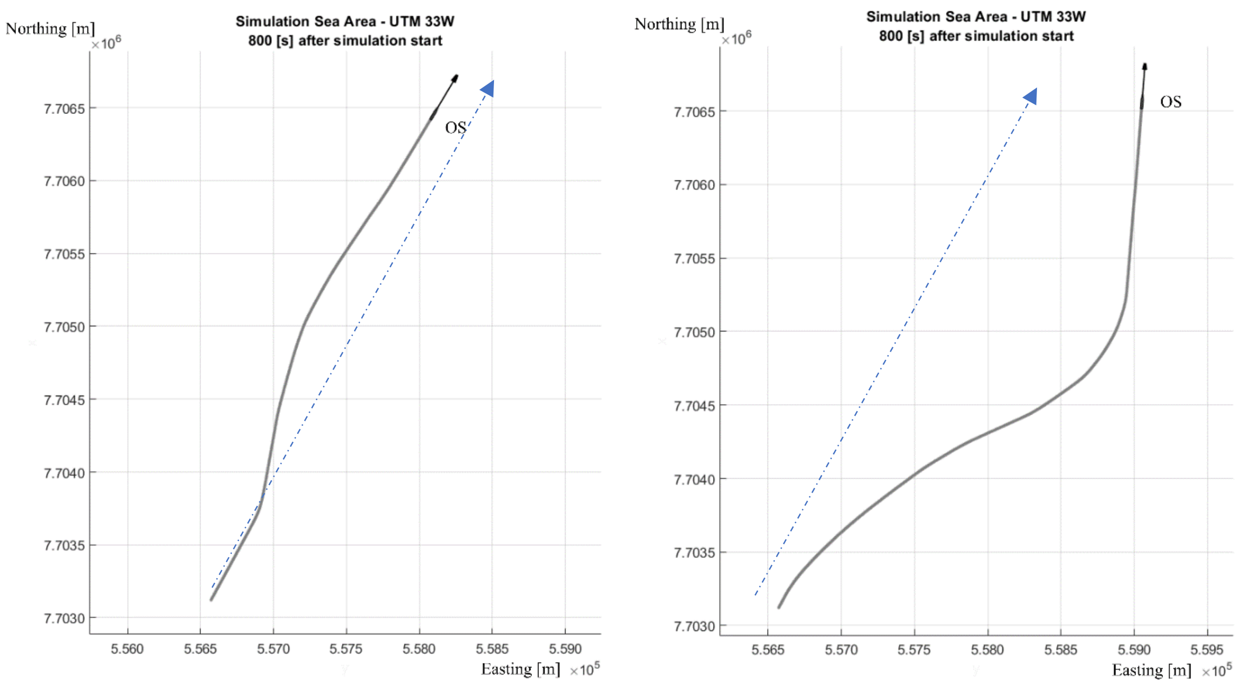


Figure 11(a) OS trajectory in Case 1 from Operator A   Figure 11(b) OS trajectory in Case 2 from Operator B

Figure 11. Comparison of maneuvers from the beginning to 800 seconds. (the original course is shown with a blue dash arrow)

5.4 Discussion and Conclusion

The case study conducted in the UiT bridge simulator offers valuable insights into potential issues that may arise when employing remote operation platforms like the designed OOC for future remotely-controlled vessels. As demonstrated in the case study, both cases present challenges in the first level of SA—the perception of relevant information in the sea environment. The source of information is solely from radar systems or combined with limited vision, which differs significantly from the navigators onboard visual perception. These variations in perceiving target ships in a sea environment may result in diverse understandings of the current situation and potential predictions made by operators in the OOC.

The simulated maneuvering in Case 1 highlights the unique aspects of maritime navigation. If the OS strictly adheres to COLREGs, it should function as the give-way vessel and execute a starboard turn. However, it is crucial to acknowledge that the decision-making process in maritime navigation is often more intricate and occasionally ambiguous compared to land transportation, which is regulated by roads and traffic signals. In practical terms, conventional navigation usually involves ship-to-ship communication before implementing avoidance strategies. Manned ships can communicate swiftly via radio, flares, or sirens. However, no established communication standard exists in cases involving remote-controlled ships. Since operator staff are not physically present on-board in remotely operated ships, communication with other target ships is significantly different from the conventional scenarios. Case 1 illustrates a scenario where the operator of the remotely operated ship makes decisions independently without communicating with the target ships. Such behavior has the potential to confuse nearby TS and result in misunderstandings. The closed encounter situations resulting in Case 1 also suggest the necessity of considering a relevant Vessel Emergency Plan (VEP) for remotely operated ships. Given the absence of personnel onboard, the OOC should be able to activate and execute the VEP. This also poses a challenge to the development of autonomous ships.

This case study recommends establishing a vessel domain for remotely controlled ships, mainly when operators in the OOC have limited visibility. As demonstrated in Figure 12, despite Ship B following the COLREGs and executing a starboard turn, it is predictable that when Ship B passes to the port side of Ship A, it falls directly within the blind spot of limited vision. Ship A's inability to spot Ship B at close range visually can potentially threaten both ships. Under such circumstances, Ship A could make a slight starboard adjustment to uphold a clear vessel domain, guaranteeing sufficient space and a more considerable time frame to respond to unexpected occurrences.

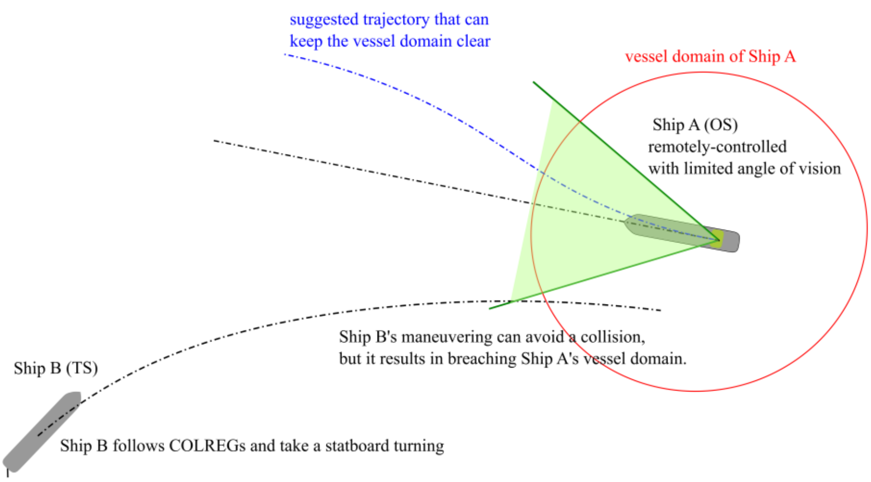


Figure 12. The encounter situation which involves a remotely controlled ship

The existence of vessel domains can cause navigational constraints that may surpass human empirical computation abilities. Therefore, assistance from the OOC can become crucial in addressing this aspect. One possible supportive function is the advanced ship predictors, which can precisely predict ship trajectories locally and globally [43][44], and that can be used to detect trajectory intersections of vessel domain situations as possible collisions risk ship encounters. Such predictions not only ensure safety but also positively impact economics and costs. In Case 2, despite choosing a safer route and making careful maneuvers, it resulted in greater mileage and notable alterations to the course. A frequent occurrence of such scenarios can escalate overall costs. Therefore, while prioritizing safety during navigation, the OOC should also aim to optimize routes as much as possible.

6. CONCLUSION

The current study provides an overview of autonomous shipping technology and its needs from an OOC operational perspective. Furthermore, this study elaborates the role of OOC and operators in adopting required autonomous technology into the shipping industry. The OOC will be developed from a functional support perspective to monitor and ensure safe operation in autonomous vessels according to international laws and human-in-the-loop-like applications. The proposed working scheme and operator action loop provide future direction for R&D in this domain. For adopting such approach, this study also provides direction on future maritime workforce training requirements according to future autonomous vessel's technology. The case study simulates vessels remotely operated by the OOC operators using a bridge simulator environment. Results indicate the advantages and drawbacks of utilizing different system information to operate ships in a simulated environment. This will help to design a more robust and feasible future OOC. The OOC may solve most of the maritime industry's challenges and regulatory authorities' concerns at all autonomy levels. The main contribution of this research study can be defined as the knowledge and competence development on the role of the OOC and operators.

ACKNOWLEDGMENTS: This work is supported by the Norwegian Ministry of Education and Research, Norway under the MARKOM II project title "Onshore Operation Center for Remotely Controlled Vessels (OOC)" (with the contract number PMK-2022\10014.) that is a development project for maritime competence established by the Norwegian Ministry of Education and Research in cooperation with the Norwegian Ministry of Trade, Industry and Fisheries.

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