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

M. Adnan
Department of Technology and Safety, UiT The Arctic University of Norway, Norway

L.P. Perera
Department of Technology and Safety, UiT The Arctic University of Norway, Norway
SINTEF Digital, SINTEF AS, Oslo, Norway AS, Oslo, Norway

ABSTRACT: To navigate, Maritime Autonomous Surface Ships (MASSs) must be able to determine their states. i.e., the positions and velocities, etc., by utilizing onboard IoT, and ship intelligence systems. Autonomous ship navigation can heavily rely on machine learning algorithms that can predict how vessels will maneuver in the future, based on past behavior, where vessel state estimation can play a main role. Due to multiple factors such as system failures, bad weather situations, local geographical conditions, and lack of system robustness, sometimes intelligent ship navigation systems may degrade the performance, i.e., may fail to respond or fail to find the safest route. To ensure safe and optimum operations in a selected sea area, MASSs need the necessary supporting tools for safe navigation. In this study, a navigational support framework of navigation monitoring, guidance, and control for MASS is presented in the aspects of onshore operation centers (OOCs), including their respective challenges and possible solutions.

1 INTRODUCTION

The concept of autonomous shipping has received attention recently due to its multiple benefits over conventional shipping. On the other hand, the crew shortage in the maritime domain is another major consideration and that can shift conventional shipping to automated shipping. The willingness of workers to perform maritime professions is decreasing, and there is an irreversible drift in the maritime domain due to long periods away from land, harsh sea environment conditions, communication difficulties, etc. The shortage of experienced sailors can compromise the safety considerations of the maritime industry. Handling the decreasing interest of humans in the maritime profession needs to be tackled through accelerated development in advanced automated and AI-based sensors and systems (Nguyen (2019)).

Autonomous ships must be able to make intelligent navigation decisions based on the information gathered from their sensors and perception systems, i.e., ship intelligence. This involves improving sophisticated, intelligent control algorithms and systems that can also be influenced by multiple factors, such as the vessel's current position & speed, distance to other vessels in its vicinity, rough weather, and sea conditions. Autonomous ships must be able to communicate with other vessels and onshore operation centers (OOC) to exchange information and coordinate vessel movements for safe navigation. This requires the development of a reliable and secure communication framework that can be operated under various weather and navigation conditions (Noel et al. 2019).

The research and development studies in autonomous ship navigation can be clustered into two major categories based on classical mechanics and soft computing. The classical mechanics methods are based on mathematical theories and models and soft computing methods belong to advanced artificial intelligence (AI) and machine learning (ML) techniques (Perera et al. 2014). System-based navigation is an emerging technology not only in shipping, especially for autonomous shipping but also in the automotive industry (Divakarla et al. 2019). It is a requirement that this technology should improve safety and trustworthiness in shipping traffic management type applications. The maritime industry adopts the standardized Automatic Identification System (AIS) to know the exact position and location of vessel operations (Ozoga & Montewka (2018)) and that should be further integrated into future shipping.

This study proposes a navigation support framework that can consist of various considerations. The cutting-edge satellite technology available through GNSS technology has allowed highly accurate vessel positions for future vessels.

Since emission reduction is the major concern in future shipping operations. An important part of the fuel consumption monitoring of these vessels can be important, where respective fuel monitoring systems should be placed. Vessel monitoring systems (VMS) can be an integrated component supported by communication facilities that can observe vessels such as cargo delivery, fishing boats, and even passenger ships (Deng (2015)). The vessel traffic service (VTS) assists in areas with high traffic density, where support is required. However, the VTS will not take control over vessels under the current situation.

However, that concept can be implemented concerning autonomous shipping. Furthermore, there is a need for an organizing mechanism for the traffic

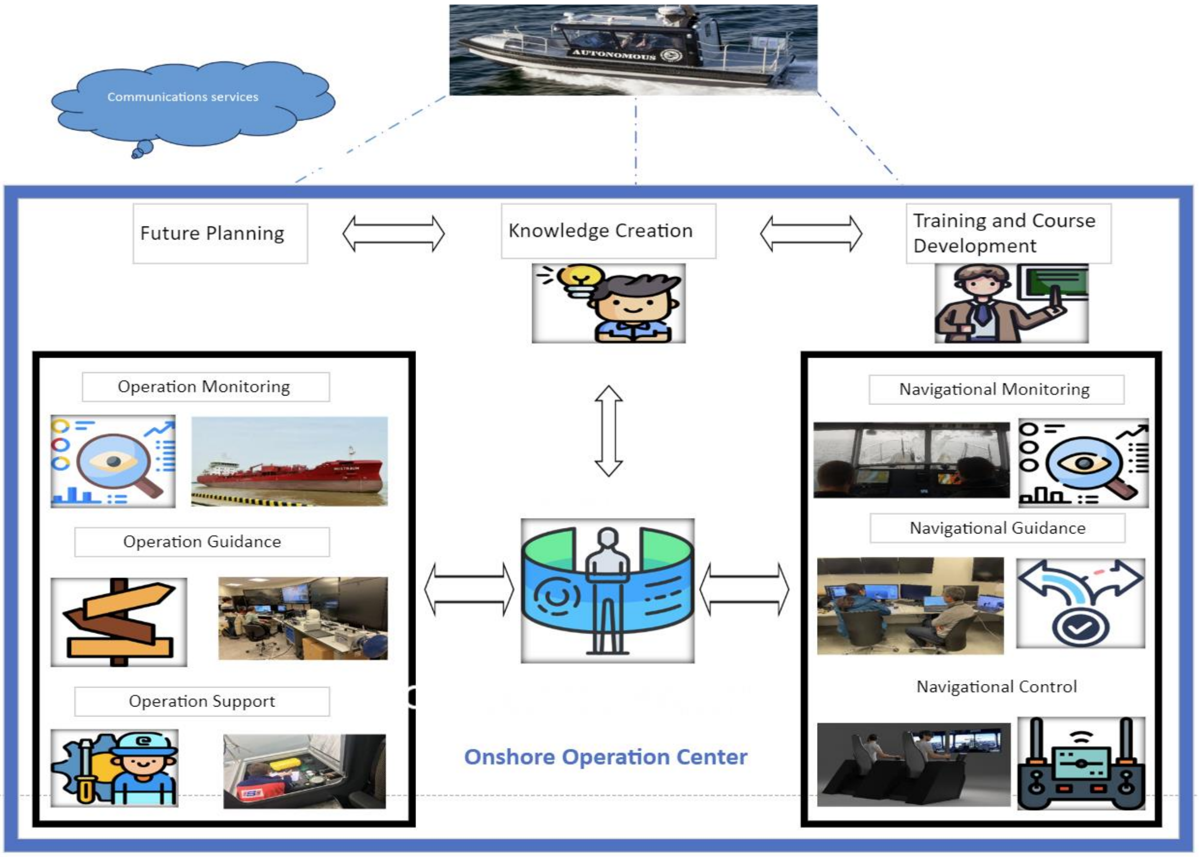

Figure. 1 Onshore Operation Center

when resources become insufficient (Porathe (2016)). In such cases, a navigation support framework is needed to handle such situations safely and efficiently. Therefore, appropriate technologies are crucial for vessels involved with human lives, i.e., cruise ships, because of the many human lives on board. One should note that shipping accidents can result in many losses of human lives, environmental damage, economic devastations, etc.

The concept of E-Navigation based route planning has been considered by the shipping industry previously as a challenging task. The weather conditions can always influence vessel seakeeping and maneuvering conditions. These meteorological factors can influence ocean-going vessels, especially in rough weather conditions. Therefore, an intelligent advanced predictor system is needed to forecast the required resources on each selected shipping route, such as bunker fuel expenditure, sailing time, and assessment of fulfilled ocean-sea conditions at each waypoint.

Implementing ship fuel consumption-related solutions in autonomous shipping needs human-in-the-loop systems for better planning, i.e. resource management, and optimal solutions, at least for the near future. In navigation monitoring, it is considered that there is a need for advanced condition monitoring and condition-based maintenance type applications of marine engine and propulsion systems to support such autonomous vessels (Orlandi et al. 2021). In such situations, the OOC operators can observe the voyage planning phase and make navigation decisions based on weather and vessel traffic information for safe navigation.

The incompatibility issues between the existing maritime infrastructure and autonomous vessels are considerable. To navigate safely, autonomous navigation systems may need help from experienced human crew, especially in complex operation environments, i.e. a mixed environment where manned, autonomous, and remotely controlled vessels are interacting, with rough weather conditions. The currently available technology may not be able to reduce maritime accidents significantly in such environments. However, autonomous vessels should have the potential to handle such kinds of accidents better than humans. Such vessels also still face multiple challenges, such as system trustworthiness and cyber security issues under possible communication failure situations.

Utilizing autonomous ships in all types of environments is expected and therefore still required to solve multiple challenges concerning the safety and operational requirements of such ships, i.e., operating area local law compliance, safe environment, other near-operated vessels, cargo, etc., (Felski & Zwolak (2020)). These autonomous navigation technology failures can occur due to several reasons, i.e., low visibility of the operating area, sensor failure situations, extreme weather, wrong system prediction, etc. Such conditions create the need for OOCs that should be facilitated with a navigation support framework to facilitate autonomous vessels in such situations with higher safety considerations since maritime transport demands a high safety standard (Nguyen (2018)).

To overcome these technological gaps, the proposed navigational support framework for MASS under OOCs will play an essential role in this regard. The proposed navigational support framework is a theoretical contribution to provide an overview of the concept of OOCs for future MASS operation control. The study highlights the major functions required, challenges, and viable solutions regarding navigational monitoring, guidance, and support aspects. In the next part of this paper, a high-level overview of the developed steps in an OOC and navigational support framework is presented to support autonomous shipping in the future.

2 ONSHORE OPERATION CENTER DESIGN

Various research and industrial consortiums are on the path towards developing the concept of onshore-based operation center infrastructure to support autonomous vessels efficiently and safely. Hence, an advanced maritime remote-control structure is needed to support autonomous vessels, especially in fully autonomous mode. The concept of onshore operation centers will play a key role in accepting autonomous navigation socially and technically, by enhancing the safety conditions of autonomous vessels.

The Arctic University of Norway (UiT) is also developing the same concept known as an onshore operation center (OOC) to support the operation of a small-scale research vessel, as shown in Figure 1. It is expected that this vessel in autonomous navigation will be utilized on a small scale for short sea shipping, i.e. the main reason for selecting small-scale vessels for this research study. One should note that the OOC will help support both operational and navigation aspects of autonomous ships in the future. It has been categorized as the navigation support framework and that can also be utilized to create the required knowledge that will be utilized to train future OOC operators. That is the main contribution of this study.

The OOC will be equipped with data analysis tools that can be utilized with data science and machine learning techniques to provide information to the OOC operator for planning and making decisions while handling autonomous vessels at sea. It is expected that most of the navigation and operation activities in autonomous vessels will be done through the OOC soon.

Based on onboard sensor information, all planning and decision-making processes related to vessel navigation and operation will be done through OOCs. Critical navigation situations, i.e., complex, and narrow passage navigation, can be done through OOC human operators, i.e., humans in the loop system, to avoid any collision in critical sea areas, as required.

The continuous navigational monitoring functionality of the OOC will play a vital role in this regard. This study focuses on introducing the navigational framework of the OOC to support the safe and secure navigation of autonomous vessels, as shown in Fig. 2. Furthermore, this study will highlight an overview of autonomous navigation, challenges, and viable solutions that can be implemented in the OOC platform. The OOC navigation framework is comprised of listed three significant elements:

1. Navigation Monitoring
2. Navigation Guidance
3. Navigation Control

Various data handling capabilities should be facilitated onboard vessels to handle the respective data sets that are collected onboard vessels. Modern vessels are designed to collect and communicate such data sets, but future, these data sets should be analyzed onboard vessels to make appropriate decisions. In navigation monitoring, there is future work for developing a digital helmsman, i.e., a digital captain-like cloned from human navigator vision and actions, which will navigate future vessels.

It is expected that ocean-going vessels will collect such datasets for real-world ship navigation and utilize them to develop digital navigators. Deep learning-based neural networks, i.e., machine learning algorithms, will be utilized for developing such digital navigators (Perera & MO (2018)). One should also be noted that such data sets can also be created under a bridge simulator environment. In the next session, we will explain each element of onshore operations concerning navigation in detail, including their importance, challenges, and possible solutions.

3 OOC NAVIGATIONAL SUPPORT FRAMEWORK

3.1 *Navigation Monitoring:*

Navigation monitoring in autonomous ships refers to monitoring their movements and position to ensure that they follow their intended course and stay within their designated operational area, specifically under rough weather conditions. Navigation monitoring typically involves tracking the vessel's locations, speeds, and directions, i.e., course and heading, using GPS, radar, lidar, and other navigational aids such as electronic chart display systems (ECDIS) that allow the ship to locate its surroundings in a digital environment. The onboard sensor data can be analyzed and

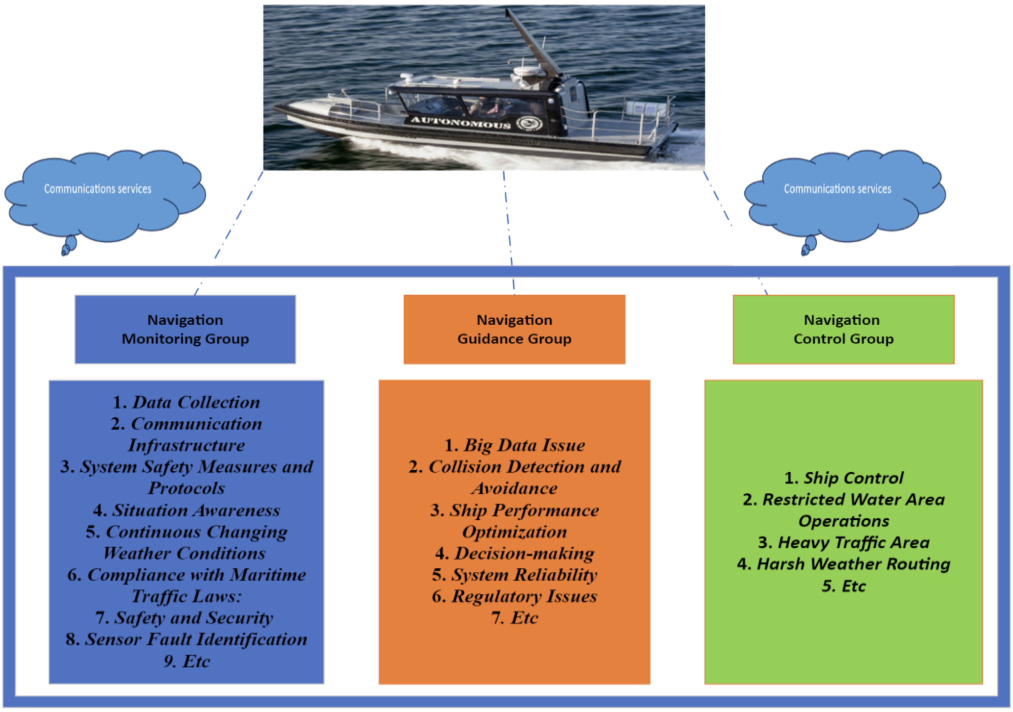

Figure 2. Navigational Support Framework for OOC

utilized by OOC operators to navigate future vessels safely and more efficiently, specifically in crises. This information will be shared with maritime authorities and local administration to issue warnings or instructions to avoid hazardous situations or major obstacles. Hence, navigation monitoring is a critical step in future shipping operations, and it will be a part of the future maritime laws that are related to navigation safety including vessel traffic situations. It will help to operate future vessels according to a set of rules and regulations, concerning vessel behavior in certain restricted operating areas.

A network of onboard sensors or IoT must be integrated in a time-synchronized manner to control future vessels, and that information should also be communicated to OOCs. In either case, autonomous vessels should be able to provide online updates on the ship's position, course, and speed and alert the operators in OOCs regarding any potential problems or deviations from the intended route. For the safety purpose of the self-directed vessel, the information system's acquisition and perception are essentially related to navigation monitoring. To improve the integrity of autonomous navigation the respective tasks can be handled by AI-based machine learning algorithms that can be adopted by various modern technologies (Ma et al. 2020). Navigation monitoring is essential in an autonomous ship for several reasons, some of which are listed below including challenges and possible solutions in detail. The respective navigation monitoring challenges can be categorized as: i) Data Collection, ii) Sensor Fault Identification, iii) Robust Communication Infrastructure, iv) System Safety Measures and Protocols v) Remote Situation Awareness, vi) Continuous Changing Weather Conditions, vii) Compliance with Maritime Traffic Laws and viii) Safety and Security

Navigation Monitoring Solutions :

Data Collection and its Applications: Navigation monitoring can also collect valuable data by utilizing different sensors, such as cameras and IoT devices in the onboard ship system. The navigation monitoring data can be used to improve its energy efficiency and identify optimal ship operation conditions. That can also be used to optimize ship's routes and vessel speeds, especially in emission control areas to improve fuel consumption and reduce emissions. An accurate position, vessel speed, and heading information are necessary to ensure the vessels reach their destination as planned under route planning type applications. The demand for exact position data is much more critical when a ship departs or arrives at a harbor at a given time interval.

Hence, a data collection system is crucial in having such information from onboard sensors or IoT. Various machine learning techniques can be applied to analyze such data sets e.g., the principal component analysis or singular values decomposition method can be one solution for detecting the large dataset's hidden structure to observe ship navigation/trajectory information (Perera (2016), Murray & Perera (2022)).

Sensor Fault Identification: In general, advanced systems that can detect possible sensor or system failures should be a part of future autonomous shipping. Due to the absence of onboard crew in autonomous ships, any mitigation actions on potential sensor or system failures can be complex. Sensor or system fault detection is critical because the automation system relies on sensor data for decision-making and systems for decision execution.

Identifying, isolating, and recovering data anomalies can improve the integrity of ship navigation from the routing perspective. A fault detection scheme can be utilized to detect the outliers of sensor data that can be outliers of the respective parameters (Perera (2016)). Such instant fault detection, isolation, and recovery applications can support future ship navigation. Immediate detection of system failures in autonomous ships based on sensor failure information can assist in preventing critical ship navigation situations (Perera (2016)).

Advanced data analysis frameworks can be developed to capture, isolate, and recover sensor faults and system abnormal events at the initial stage that can eventually support future ship navigation requirements. The sensor's generated information, i.e., an essential step in autonomous navigation systems, can also be supported through OOCs, i.e., in more critical situations, to ensure reliability for the decision-making process.

Robust Communication Infrastructure: Autonomous ships must be able to communicate with other vessels and shore-based systems to send and receive information that relates to the respective journey. This requires reliable and secure communication schemes that can functions in rough weather conditions. Communication without delay between ships and OOCs is required continuously during the ship operation phase. However, navigation systems can be developed to cope with short-time communication interruptions, specifically in non-critical ship navigation situations.

The transmission cost of large-scale data sets can be higher due to expensive satellite communication systems. That can eventually challenge autonomous ship navigation as one of the main concerns for the maritime sector. In deep learning, some appropriate solutions to reduce the size of data sets can be implemented to handle such tasks; the auto-encoder technique has shown great potential for data compression, especially with sensor data. The architecture of the autoencoding method for compressing and decompressing data sets related to vessel operation and navigation parameters must be transmitted over communication networks for the OOC operator's overview (Perera & MO (2018)). That process can also help to reduce and recover data anomalies.

System Safety Measures and Protocols: Ensuring the trustworthiness of autonomous operations in future vessels is crucial. This can be achieved by developing robust safety measures and protocol monitoring schemes for detecting failures or malfunctions at various system levels, as well as guaranteeing appropriate system behavior in crises.

The ship monitoring systems can also benefit from the AIS at a global level with the Long-Range Identification and Tracking (LRIT) scheme. The standardized support model adoption in autonomous systems makes development easier and faster by integrating advanced automation and navigation systems with onboard processes.

While various system developers integrate such automation and navigation systems, therefore having standardized modular systems for such systems can reduce system-level faults and failures. Therefore, having a proper system architecture with standardized modular systems can expedite the development of autonomous shipping (Chen et al. 2022).

Remote Situation Awareness: The probability of an operator or system losing sufficient understanding of situational awareness in autonomous ship navigation is substantially greater than in conventional shipping due to the absence of the onboard crew. Autonomous vessels operating through OOCs will introduce higher navigation safety issues because of the lack of understanding of the operating environment information. Therefore, transforming the navigation monitoring information into precise knowledge of the respective situational awareness should be done, where the respective technologies can be adopted adequately.

Autonomous ships must be able to perceive and interpret their surroundings as a part of situational awareness to navigate safely and efficiently. This involves using a variety of sensors and perception algorithms to identify and monitor other vessels, obstacles, and other relevant features of the environment. The beneficial way to navigate is to plan the passage as safely as possible to the sideways, i.e., digital ship routes, of the channel to prevent a last-minute evasive manoeuvre. However, unexpected situations may lead to such maneuvers and future vessels should also have the capabilities to overcome such situations. On the one hand, autonomous vessels can increase human life's safety and security because they are unmanned or understaffed (Porathe (2016)), but that can also raise navigation safety issues, specifically in a mixed navigation environment.

These sensors can be combined with advanced perception algorithms to accurately interpret and understand the environment, including other vessels and obstacles. The vessels should have reliable system intelligence in making their conclusions and determining procedures. The vessel navigation systems should have adequate reliability to operate, i.e. the decision made by digital navigator-type technology.

Inspired by the recent adaptation of autonomous and automated systems in other transport modes, i.e., digital drivers in driverless cars, it also has influenced the development and utilization of autonomous technology in the shipping industry. Since there are many challenges in making autonomous shipping a reality, there are various discussions on these disruptive autonomous technologies (Zhou et al. 2019).

Continuous Changing Weather Conditions: The radar data can be cluttered during rough weather conditions. In such situations, autonomous navigation systems can be challenged by sensor noise conditions, therefore the OOC operator's help can be crucial for maintaining safe navigation conditions. Due to changing weather conditions, autonomous systems may not perform the respective tasks as per the defined criteria due to harsh environmental factors that can affect the system's efficiency and performance. Researchers have designed and developed different techniques, such as rain and snow suppression algorithms, to enhance the performance of radar object observation in severe weather conditions (Qin & Chen (2019)).

Compliance with Maritime Traffic Laws: Navigation monitoring can also help to ensure that ships stay within their designated ship routes and comply with relevant local and international regulations. This is especially important in situations, where vessels operating in restricted or sensitive areas, such as war zones, and in the vicinity of ports or other marine infrastructure; Aerial drones have been used by various research groups to monitor ship emissions in harbour areas to enforce the environmental laws (Deng et al. 2022).

Safety and Security: One of the primary goals of navigation monitoring is to ensure the safety of the vessel, cargo, and its crew, if any, onboard. One should note that there may be a requirement for the onboard crew in future vessels, to maintain and operate complex marine engines, specifically in deep-sea shipping.

By continuously monitoring the ship's position and movements, detecting, and preventing potential collisions with other vessels or obstacles is possible. Online navigational safety monitoring systems have been developed, such as LNG ship risk in inland waters. The global maritime distress and safety system (GMDSS) system uses maritime security data and a shared communication network to catch corrupted signals from vessels (Deng (2015)). Autonomous vessels will encounter distinct circumstances; the OOC operators should have knowledge and experience in handling such situations in a safe navigation manner (Kim et al. 2022).To improve the situation awareness of OOC operators in a mixed environment, the requirements of modern technologies and machine learning algorithms are essential (Zhou et al. 2019).

According to the Piracy Reporting Center of the International Maritime Bureau (IMB), oceanic piracy has risen for several years; maritime transport now faces increased risks and security issues (Kim et al. 2022). VMS is the most used framework in all types of vessels. Using the VMS system makes it easier to locate the ship and find abnormalities in the operation of vessels at sea. Preventing and minimizing the impact of piracy can be a difficult process, however, required technologies should be developed to support autonomous navigation in shipping.

3.2 *Navigation Guidance:*

Navigation guidance refers to the algorithms, systems, and protocols used to guide the vessel's movements and ensure that it navigates safely and efficiently. The OOC operators can provide navigation guidance where autonomous systems may fail, resulting in unexpected safety critical situations. The navigation system needs continuous guidance to operate safely and securely in rough weather, narrow passages, high-traffic zones, and port areas for future vessels.

The autonomous guidance and navigation (AGN) system is expected to be a key element in upcoming maritime navigation due to its more secure features. The verdict shows the worth of AGN systems in sea navigation and human observations of their abilities and requirements for future development. Automatic pilot systems are the chief development part of AGN systems, and their applications have been the dream of shipbuilders for numerous years. Recent developments in sensors, computing infrastructure, intelligent equipment or devices, and AI-based systems make the desire into reality in next-generation AGN systems (Smierzchalski (1998), Ahmed & Hasegawa (2016)). Avoiding accidents at sea is one of the core responsibilities of secure shipping that attracts considerable attention (Statheros et al. 2008). Intelligent systems make automatic maneuvering possible by developing intelligent systems for guidance, navigation, and control (Li et al. 2021).

If we are going to answer the question of ‘Why is Navigation Guidance important?’: Navigation guidance is essential in autonomous ships for several reasons. For example, safeguarding the secure navigation of autonomous vessels is paramount. Ship collisions and groundings are still the most significant causes of accidents. According to COLREG, collision prevention is critical when dealing with autonomous ships (Vagale et al. 2021).

Collisions at sea cause significant disturbances regarding safety, security, and damage. For example, crashes in numerous circumstances direct to irreversible environmental and economic damages. To minimize the risk of collision, some decision support and control systems based on the human-in-loop concept are recommended to be set up on vessels. It will help the vessel navigate through complicated crossings with the help of the OOC navigational operator’s support. Most seaports have Vessel traffic services (VTS) systems to assess the secure paths of ships arriving and departing the port (Zhang et al . 2015).

Sea conditions and weather are highly variable and uncertain during sailing in cold climates, i.e., arctic ship navigation. This will raise the accident risk over the next couple of years, mainly at the end of the shipping season (Bolbot et al. 2023).

Navigation guidance in autonomous shipping faces multiple challenges. One of the significant functions of OOCs is to provide navigation guidance to the shipping fleet for safe operation. Some of the challenges and their possible solution are mentioned below. The navigation guidance challenges can be categorized as: i) Big Data Issue, ii) Collision Detection and Avoidance, iii) Ship Performance Optimization, iv) Decision-making, v) System Reliability and v) Regulatory issues.

Navigation Guidance Solutions:

Big Data Issue: The industrial IoT collects large-scale data sets called 'Big Data' and that can also introduce various challenges. The shipping industry utilizes such datasets to understand vessel behavior, which can be used to optimize decision-making processes such as route planning, optimal engine operations, condition-based maintenance, navigation guidance, etc.

Data processing can always be associated with higher costs, which can be associated with low-quality data sets. The existing IT networks should be further improved to support the decision-making process of autonomous ships, which should be more robust and accessible based on real-time sensor data (Perera & Mo (2018)).

The big data challenge can be handled by developing advanced analytics associated with machine learning algorithms. Big data can be used for predictive analysis, such as predicting additional costs related to the ship's lifecycle. Based on the analyzed data, robust decisions can be made to control the vessel's operation in the future. Taking such actions by the OOC can improve organizational functions and decision-making capabilities Perera (2017).

Collision Detection and Avoidance : The problem of ship route planning, formulation of appropriate cost functions, and consideration of topological and kinematic constraints are still challenging tasks to avoid collision at sea. Intelligent decision-making capabilities based on navigation guidance from the OOC must be a unified part of the upcoming AGN system to advance autonomous sea navigation systems. Researchers already developed various techniques to handle such challenges (Perera et al. (2009), Zaccone & Martelli (2020)).

The goal is to significantly improve waterway safety by avoiding collisions, relieving the navigator of tedious routine work, and supporting challenging situations, especially at night or in fog conditions at sea (Zaccone (2021), Nielsen & Jensen (2011)). Based on AI techniques, several methods have been developed to overcome ship collision situations, such as fuzzy logic (Zhang et al . 2015), neural networks, feedback controllers for speed control & path tracking (Vagale et al. 2021) and dynamic predictive guidance technique (Kozynchenko, al & Kozynchenko (2018)). These techniques are introduced for guidance systems to increase the effect of ship course track retention (Kurowski et al. 2019). With the help of these available solutions, OOC operators can provide navigation guidance more robustly for safe navigation at sea. The humans in the loop situation will significantly enhance the robustness of autonomous navigation in shipping.

Ship Performance Optimization: Navigation guidance can also help to optimize ship routes and vessel speeds. Continuously updating the ship's position and movements based on current sea conditions to avoid unfavorable conditions and take necessary fuel-saving measures will increase the ship's energy efficiency. It is possible to adjust the route to avoid unfavorable weather conditions or other obstacles, which can help to reduce fuel consumption and operational costs. Ship energy efficiency is also be associated with vessel fuel consumption, where the respective emissions should be reduced. Fuel cost is a significant part of the vessel operating cost; optimizing fuel consumption can increase profit and other economic benefits while reducing the respective emissions (Chen et al. 2022).

Reliable path planning can be considered a dynamic optimization approach that can have a challenging solution. The navigation guidance functions will ensure the ship's optimization capabilities regarding operational aspects like on-time cargo delivery, fuel optimization through route planning guidance and harbor operations, and safe operation guarantees.

Decision-making: The decision-making technology in autonomous vessels should be robust enough because that can play a crucial role in oceanic autonomy. Autonomous ships must be able to make intelligent navigation decisions based on the information they have gathered from their sensors and perception systems. This requires the development of sophisticated decision-making algorithms that can consider multiple factors, such as the ship's current position and speed conditions and the weather and sea conditions; navigational charts information including water depths, average topographies of the seabed, directional risks, assistances to routing, sea current data, harbors harbors, buildings, and bridges, etc. (Zhou et al. 2019). The OOC operators need to monitor the navigation plan continuously and will interfere with the system-generated decision-making as required, specifically in critical navigation sea areas and conditions.

System Reliability: Guaranteeing the reliability consistency of autonomous vessel system operations is a critical challenge. This includes developing strategies and protocols for detecting and responding to failures or malfunctions and developing robust safety measures to prevent accidents and injuries. Without the OOC's help, it is sometimes impossible for an autonomous system to handle such situations due to multiple factors such as a political situation or war zone, system functions failure or response failure, future weather conditions, and those factors that are usually not modeled into the system quickly. Navigation guidance is one of the essential functions OOC operators perform to enhance the security and trustworthiness of autonomous ship operations.

Regulatory issues: The development and placement of autonomous vessels, including their operations, are subject to various legal and regulatory frameworks, including liability, insurance, and safety considerations. Handling these issues will be an essential core challenge for the shipping industry in developing and deploying autonomous navigation systems. This can be supported through OOCs by careful planning and compliance with relevant laws and regulations, as well as working with regulatory bodies to make sure that autonomous vessels are safer to navigate (Ringbom & Veel (2017)).

The navigation guidance functions will solve legal and regulatory problems through the OOC operators. The OOC operators can utilize the navigation guidance functions in case of emergencies or system failure occur. These legal and regulatory issues are critical challenges in deploying autonomous ships in the future (Rodseth & Burmeister (2015)). Through the OOC human-in-the-loop-system design, many legal issues s can be solved.

3.3 *Navigation Control*

There is a need to develop intelligent navigation control systems to support future ship operations through OOCs, especially when making decisions in complex navigation situations, which will directly contribute to navigation safety. The impact of waves in coarse weather conditions is one of the circumstances that impair the operational efficiency of ships. Hence, deliberate reasoning in the decision-making process for ship handling plays an essential role in navigation. The OOC operators will receive support from navigation systems with real-time sensor data and advanced analytics to ensure vessel safety concerns (Mousazadeh et al. 2018).

The ship course controllers were usually designed with the assumption of a constant vessel speed. However, sailing vessels typically need to reduce or adjust the speed to formulate berthing type maneuvers in the fairway area. The existing course tracking system tracks the ship in an open sea area by assuming the speed is constant, which cannot be used to track and navigate vessels in fairway areas because ship speed is continuously changing (Min & Zhang (2021)). Detecting and avoiding other vessel groups sailing nearby is one of the main jobs in ship navigation, as near-miss situations with them can potentially cause serious risks to ship collisions (Perera et al. 2012). In such situations, navigation control & and support are essential functions to continue safe ship operations.

In adverse weather conditions, each maneuver must also be checked to evaluate whether it is safe & secure in terms of ship steadiness point of view. In such situations, OOC navigation control is needed by a human-in-the-loop system to handle such critical circumstances. The OOC operators may utilize some advanced intelligent AI-based system to predict the future outcome based on the current situation from the analytical approaches before providing any recommendations or support for necessary navigation control. This will enhance the robustness of the navigation system significantly through the proposed OOC navigational support framework.

If we are going to answer the question of 'Why is Navigation control important?': The navigation control functions of an autonomous ship is essential for ensuring the safety and efficiency of its operations where the automatic system fails to respond. For example, it can help to prevent the ship from running aground or colliding with other vessels or obstacles, and it can also help to optimize the ship's route and speed to minimize fuel consumption and additional costs. There is a need to build a prototype system that can monitor several parameters related to the movement of ships and process this data to provide OOC operators with the consequences of different decisions about the ship's handling.

The Navigation control system is still under development, and it can utilize the AI-based decision support system to solve complex situations with sample and reliable solutions. Some existing systems use the idea of a Multi-ARPA (MARPA) system (Tsou et al. (2010), Nishizaki et al. (2018). The driving force behind the OOC's proposed build architecture is the changing international nature of shipping that needs to create standards for autonomous ship control and information exchange to increase efficiency further, reduce the possibility of accidents, decrease greenhouse gas (GHG) emissions, and enhance safety in the maritime industry (Kawaguchi et al. 2009). Some of the navigation control challenges and viable solutions can be categorized as: i) Ship Control, ii) Operations in Restricted Navigation Areas, ii) Heavy Traffic Areas and iv) Harsh Area Weather Routing

Navigation Control Solutions :

Ship Control: Some navigation regions may need ship control support for safe operations, like narrow passages, severe weather conditions, low visibility areas, sensor system failure situations, etc. It is optionally possible to display only COLREGS-compliant maneuvers through smart decision support systems. The emplacement of these kinds of data allows the navigator to select effective maneuvers in situations where choices are restricted by weather conditions, where the ship stability features of ocean-going vessels can be challenged (Rødseth (2011)).

The OOC operators can use advanced sensors-based systems for all motion measurements and wave spectrum estimation schemes, approximating confined sea states in real-time to provide optimum navigation control of autonomous ships whenever needed (Mousazadeh et al. 2018). Rudder control keeps vessels on the planned track, and the vessel's speed is reduced slowly to reach the anchorage area during berthing situations. At low speeds, rudder control may not work adequately, and vessels can lose their maneuvering capabilities. Then, the vessel heading is adjusted using bow thrusters supported by auxiliary engines (Min & Zhang (2021)). The OOC team must be ready for necessary navigation control support in all these situations.

The advanced analytics system makes it possible to estimate the navigation threat, which will help for safe maneuvers. Using only AIS data for ship collision avoidance is challenging (Szlapczynski & Krata (2018)). A navigational control system capable of AIS synthesis is needed, augmented with a mark of intellect generated from a physical model for capturing group navigation dynamics of ocean-going vessels(Ozoga & Montewka (2018)).

Operations in Restricted Water Areas: The operation in restricting water needs navigation control & support for an autonomous system via OOC in terms of speed, gas emission, etc. To handle such a situation, integration of the dynamic changes into an automatic navigation handling system is complex. Electrifying the vessel and cargo will allow marine traffic to follow and build an infrastructure that can withstand the effects of climate change. Investing in recent green technologies will also reduce emissions (Porathe (2016)). The maritime community has realized the importance of new green technology, and the e-navigation (from the International Maritime Organization - IMO) and e-Maritime (from the European Union - EU) initiatives testify to this (Zhang et al.2015).

Heavy Traffic Areas: Maritime traffic has increased exponentially in recent years expanding the possibility of ship-to-ship collisions. It could lead to one of the fatal accident’s reasons in the future if it is not handled correctly. AI-based support tools could help avoid collision by providing estimations based on sensors and prediction systems, decreasing the load on navigational operators, and enhancing maritime domain safety and security (Nilsson et al. 2009). To ensure the navigation is safe and secure in a high-traffic area, the OOC operators must take control and act on time to escape from the collision based on operating area environment information, prediction, and other vessels' behavior (Li et al. 2022).

Harsh Area Weather Routing: July to October is the lowest risk session for cargo ships conducting commercial voyages throughout arctic waters. Navigation support or recommendations in critical routes, such as the optimal safe turn angle, speed, route selection, etc., are essential. As the commercial activities on arctic routes increase significantly each year, secure and safe navigation is the main concern in the multifaceted arctic environment. Operating in such complicated areas requires continuous essential navigation control & support for a safe operation guarantee. The OOC operator will utilize the AI-based system to handle such situations. Researchers developed onboard decision support systems for safe navigation in harsh weather & sea conditions using a neural network to find the safe ship course and speeds based on the current operating sea environment parameters (Perera et al. 2012). A dynamic Bayesian network can forecast arctic waters' spatial and temporal threats, creating a chart of navigational risks of these areas’ seawater (Nilsson et al. 2009). OOC operators will provide necessary control & support to the autonomous system based on an advanced AI-analytical system through the proposed OOC navigational support framework.

4 CONCLUSION

This study presents the functionality of onshore operation centers and shows how these centers will help the future needs of maritime operations in terms of navigational support framework in autonomous shipping. This study also highlights the future control functions required in OOCs and autonomous ships regarding the navigational perspective. A comprehensive overview of navigational support methodology is proposed to address the challenges of autonomous shipping in the future. OOCs will increase the competitiveness of the maritime sector while providing required safe navigation features, i.e. humans in the loop. The data collected by sensors, satellite data, navigation systems, intelligent algorithms, and human operators in the loop make the system more robust and trustworthy. The proposed OOC navigational framework will help to reduce the risks of maritime accidents in the future and enhance the large-scale acceptance of autonomous technology by solving the concerns raised by regulatory authorities and the maritime industry.

ACKNOWLEDGEMENTS

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.) is a development program for maritime competence. The program is established by the Norwegian Ministry of Education and Research in cooperation with the Norwegian Ministry of Trade, Industry and Fisheries.

5 REFERENCES

Ahmed, Y.A. and Hasegawa, K., 2016. Fuzzy reasoned waypoint controller for automatic ship guidance. IFAC-PapersOnLine, 49(23), pp.604-609.

Bolbot, V., Theotokatos, G., Wennersberg, L.A., Faivre, J., Vassalos, D., Boulougouris, E., Jan Rødseth, Ø., Andersen, P., Pauwelyn, A.S. and Van Coillie, A., 2023. A novel risk assessment process: Application to an autonomous inland waterways ship. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability, 237(2), pp.436-458.

Chen, Q., Wu, W., Guo, Y., Li, J. and Wei, F., 2022. Environmental impact, treatment technology and monitoring system of ship domestic sewage: A review. Science of The Total Environment, 811, p.151410.

Deng, J., 2015. Real-time navigation monitoring system research for LNG-fuelled ships in inland water. Journal of Maritime Research, 12(2), pp.95-102

Divakarla, K.P., Emadi, A., Razavi, S., Habibi, S. and Yan, F., 2019. A review of autonomous vehicle technology landscape. International Journal of Electric and Hybrid Vehicles, 11(4), pp.320-345.

Deng, M., Peng, S., Xie, X., Jiang, Z., Hu, J. and Qi, Z., 2022. A diffused mini-sniffing sensor for monitoring SO2 emissions compliance of navigating ships. Sensors, 22(14), p.5198.

Felski, A. and Zwolak, K., 2020. The ocean-going autonomous ship—Challenges and threats. Journal of Marine Science and Engineering, 8(1), p.41.

International Maritime Bureau, [ONLINE] Available at: https://www.icc-ccs.org/ [Accessed 31 July 2023]

Kawaguchi, A., Inaishi, M., Kondo, H. and Kondo, M., 2009. Towards the development of intelligent navigation support systems for group shipping and global marine traffic control. IET Intelligent Transport Systems, 3(3), pp.257-267.

Kozynchenko, A.I. and Kozynchenko, S.A., 2018. Applying the dynamic predictive guidance to ship collision avoidance: Crossing case study simulation. Ocean Engineering, 164, pp.640-649.

Komianos, A., 2018. The autonomous shipping era. Operational, regulatory, and quality challenges. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 12(2).

Kurowski, M., Roy, S., Gehrt, J.J., Damerius, R., Büskens, C., Abel, D. and Jeinsch, T., 2019, June. Multi-vehicle guidance, navigation, and control towards autonomous ship manoeuvring in confined waters. In 2019 18th European Control Conference (ECC) (pp. 2559-2564). IEEE.

Kim, T.E., Perera, L.P., Sollid, M.P., Batalden, B.M. and Sydnes, A.K., 2022. Safety challenges related to autonomous ships in mixed navigational environments. WMU Journal of Maritime Affairs, 21(2), pp.141-159.

Li, X., Stephenson, S.R., Lynch, A.H., Goldstein, M.A., Bailey, D.A. and Veland, S., 2021. Arctic shipping guidance from the CMIP6 ensemble on operational and infrastructural timescales. Climatic Change, 167, pp.1-19.

Li, Z., Yao, C., Zhu, X., Gao, G. and Hu, S., 2022. A decision support model for ship navigation in Arctic waters based on dynamic risk assessment. Ocean Engineering, 244, p.110427.

Mousazadeh, H., Jafarbiglu, H., Abdolmaleki, H., Omrani, E., Monhaseri, F., Abdollahzadeh, M.R., Mohammadi-Aghdam, A., Kiapei, A., Salmani-Zakaria, Y. and Makhsoos, A., 2018. Developing a navigation, guidance and obstacle avoidance algorithm for an Unmanned Surface Vehicle (USV) by algorithms fusion. Ocean Engineering, 159, pp.56-65.

Ma, X., Shen, J., Liu, Y. and Qiao, W., 2020. A methodology to evaluate the effectiveness of intelligent ship navigational information monitoring system. IEEE Access, 8, pp.193544-193559.

Min, B. and Zhang, X., 2021. Concise robust fuzzy nonlinear feedback track-keeping control for ships using multi-technique improved LOS guidance. Ocean Engineering, 224, p.108734.

Murray, B. and Perera, L.P., 2022. Ship behaviour prediction via trajectory extraction-based clustering for maritime situation awareness. Journal of Ocean Engineering and Science, 7(1), pp.1-13.

Nilsson, R., Gärling, T. and Lützhöft, M., 2009. An experimental simulation study of advanced decision support system for ship navigation. Transportation research part F: traffic psychology and behaviour, 12(3), pp.188-197.

Nielsen, U.D. and Jensen, J.J., 2011. A novel approach for navigational guidance of ships using onboard monitoring systems. Ocean Engineering, 38(2-3), pp.444-455.

Nishizaki, C., Terayama, M., Okazaki, T. and Shoji, R., 2018, June. Development of a navigation support system to predict the new course of the ship. In 2018 World Automation Congress (WAC) (pp. 1-5). IEEE.

Nguyen, V.S., 2019. Research on a support system for automatic ship navigation in fairway. Future Internet, 11(2), p.38.

Noel, A., Shreyanka, K., Gowtham, K. and Satya, K., 2019, November. Autonomous ship navigation methods: A review. In Proceedings of the Conference Proceedings of ICMET OMAN.

Orlandi, A., Cappugi, A., Mari, R., Pasi, F. and Ortolani, A., 2021. Meteorological navigation by integrating metocean forecast data and ship performance models into an ecdis-like e-navigation prototype interface. Journal of Marine Science and Engineering, 9(5), p.502.

Ożoga, B. and Montewka, J., 2018. Towards a decision support system for maritime navigation on heavily trafficked basins. Ocean Engineering, 159, pp.88-97.

Perera, L.P., Carvalho, J.P. and Soares, C.G., 2009, November. Autonomous guidance and navigation based on the COLREGs rules and regulations of collision avoidance. In Proceedings of the international workshop advanced ship design for pollution prevention (pp. 205-216).

Perera, L.P., Rodrigues, J.M., Pascoal, R. and Soares, C.G., 2012. Development of an onboard decision support system for ship navigation under rough weather conditions. Sustainable Maritime Transportation and Exploitation of Sea Resources, 837, pp.837-844.

Perera, L.P., Ferrari, V., Santos, F.P., Hinostroza, M.A. and Soares, C.G., 2014. Experimental evaluations on ship autonomous navigation and collision avoidance by intelligent guidance. IEEE Journal of Oceanic Engineering, 40(2), pp.374-387.

Porathe, T., 2016. A navigating navigator onboard or a monitoring operator ashore? Towards safe, effective, and sustainable maritime transportation: findings from five recent EU projects. Transportation Research Procedia, 14, pp.233-242.

Perera, L.P., 2016. Statistical filter based sensor and DAQ fault detection for onboard ship performance and navigation monitoring systems. IFAC-PapersOnLine, 49(23), pp.323-328.

Perera, L.P., 2016. Marine engine centered localized models for sensor fault detection under ship performance monitoring. IFAC-PapersOnLine, 49(28), pp.91-96.

Perera, L.P., 2017. Handling big data in ship performance and navigation monitoring. Smart Ship Technology, pp.89-97.

Perera, L.P. and Mo, B., 2018. Ship performance and navigation data compression and communication under autoencoder system architecture. Journal of Ocean Engineering and Science, 3(2), pp.133-143.

Perera, L.P. and Mo, B., 2018, June. An overview of data veracity issues in ship performance and navigation monitoring. In International Conference on Offshore Mechanics and Arctic Engineering (Vol. 51333, p. V11BT12A004). American Society of Mechanical Engineers.

Qin, Y. and Chen, Y., 2019. Signal processing algorithm of ship navigation radar based on azimuth distance monitoring. International Journal of Metrology and Quality Engineering, 10, p.12.

Rødseth, Ø.J., 2011, October. A maritime ITS architecture for e-navigation and e-maritime: Supporting environment friendly ship transport. In 2011 14th International IEEE Conference on Intelligent Transportation Systems (ITSC) (pp. 1156-1161). IEEE.

Rødseth, Ø.J. and Burmeister, H.C., 2015. Risk assessment for an unmanned merchant ship. TransNav, International Journal on Marine Navigation and Safety Od Sea Transportation, 9(3), pp.357-364.

Ringbom, H.M. and Veal, R., 2017. Unmanned ships and the international regulatory framework. Journal of International Maritime Law, 23(2), pp.100-118.

Smierzchalski, R., 1998. Evolutionary guidance system for ship in collisions situation at sea. IFAC Proceedings Volumes, 31(3), pp.129-134.

Statheros, T., Howells, G. and Maier, K.M., 2008. Autonomous ship collision avoidance navigation concepts, technologies and techniques. The journal of Navigation, 61(1), pp.129-142.

Szlapczynski, R. and Krata, P., 2018. Determining and visualizing safe motion parameters of a ship navigating in severe weather conditions. Ocean Engineering, 158, pp.263-274.

Tsou, M.C., Kao, S.L. and Su, C.M., 2010. Decision support from genetic algorithms for ship collision avoidance route planning and alerts. The Journal of Navigation, 63(1), pp.167-182.

Vagale, A., Oucheikh, R., Bye, R.T., Osen, O.L. and Fossen, T.I., 2021. Path planning and collision avoidance for autonomous surface vehicles I: a review. Journal of Marine Science and Technology, pp.1-15.

Zhang, J., Zhang, D., Yan, X., Haugen, S. and Soares, C.G., 2015. A distributed anti-collision decision support formulation in multi-ship encounter situations under COLREGs. Ocean Engineering, 105, pp.336-348.

Zhang, Y., Wang, X. and Wu, H., 2015. A distributed cooperative guidance law for salvo attack of multiple anti-ship missiles. Chinese Journal of Aeronautics, 28(5), pp.1438-1450.

Zhou, X.Y., Liu, Z.J., Wu, Z.L. and Wang, F.W., 2019. Quantitative processing of situation awareness for autonomous ships navigation. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 13(1).

Zaccone, R. and Martelli, M., 2020. A collision avoidance algorithm for ship guidance applications. Journal of Marine Engineering & Technology, 19(sup1), pp.62-75.

Zaccone, R., 2021. COLREG-compliant optimal path planning for real-time guidance and control of autonomous ships. Journal of Marine Science and Engineering, 9(4), p.405.