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An Analysis of the Technical Regulatory Challenges of Autonomous Vessel Communications

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Abstract

To facilitate the implementation of autonomous vessel operations and realize the potential benefits of such technologies within the international shipping environment, the necessary communication facilities and regulatory standards must be in place.

This work contributes by providing a realistic assessment of these challenges. Through extensive research, the existing systems which autonomous/remotely operated vessels will likely have to comply and interact with have been identified. In addition, the potential communication capacity demand and availability have been reviewed.

The necessary forums to propose necessary regulatory changes have been identified. This research has been greatly supported through the input from international maritime experts who provided detailed responses to an in-depth questionnaire on these subjects. This work makes a novel contribution in furthering the understanding of the communication regulatory challenges which must be addressed to facilitate the implementation of autonomous vessel operations. The responses provided by expert survey participants within this work, provides a unique understanding and assessment of the regulatory obstacles and potential timescales facing the implementation of autonomous/remotely monitored vessels.

Language: English Keywords: Remote, Autonomous, Maritime, Shipping; Communications; Regulation; Technology

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1 Introduction

The introduction section of this thesis considers the rational and potential benefits of the introduction of autonomous and remote shipping operations. It also provides a background overview of the need for coordinated international maritime communications regulatory development to accommodate future autonomous and remote shipping operations. Such development is necessary to ensure that the data needs of future vessels are provided for in a coordinated and harmonized way.

The fundamental research problem of this thesis is introduced, that is, for autonomous and remote shipping operations to be implemented in the international maritime environment, the necessary communications regulatory framework and standards must be developed. This includes the need to develop inter-ship and ship-to-shore procedures to provide compatibility with existing vessels and safety communication systems, such as the Global Maritime Distress and Safety System (GMDSS), which requires mandatory maritime communications equipment and procedural requirements for vessels and is fundamental to safety communications for all vessels. The need to interact with other established mandatory communications which enhance safety of navigation must also be considered.

Due the high data volume that real-time monitoring and control of autonomous will entail, it is likely that the use of commercial satellite services will be proposed. However, such systems are not approved for safety communications purposes and therefore may not be acceptable within the regulatory environment. As the maritime communications legal instruments and procedures to accommodate autonomous vessel operations do not exist at present, regulatory development work within relevant international forums must be undertaken. This will be complicated as additional communication frequency bandwidth is not readily available to maritime services. The key research questions which are set out, relate to potential requirements for autonomous vessels to interact with existing maritime communications and can the needs of autonomous vessels be met under existing systems and regulations. The scope of this thesis involves an extensive literature review of existing and potential future communication requirements and a comprehensive survey of industry experts and analysis of the inputs provided.

1.1 The Rationale for Autonomous Ship Development

The case for the implementation of autonomous shipping is generally based on four potential interrelated advantages over existing vessels. These benefits are greater sustainability with reduced environmental impact, economic through cost savings, enhanced safety and solving current and future skill shortages (Porathe et al., 2014; Levander, 2017; Munim, 2019).

In relation to the potential environmental benefits and associated reduction in the running costs of autonomous vessels, the elimination or reduction of the crew on-board has significant advantages in removing the need for associated facilities. This will directly result in a reduction in energy consumption. In addition, overall vessel weight can be reduced. Without the need to include accommodation infrastructure, vessels will have increased cargo carrying capacity and increased design flexibility to reduce hull aerodynamic resistance (Ait Allal et al., 2018). These advantages could be particularly beneficial in the case of small general cargo vessels, as crew and their related facilities consume a significant proportion of overall energy consumption compared to larger vessels, such as oil tankers.

In the case of autonomous/remotely operated vessels, the initial capital expenditure may be higher than a traditional vessel due to technology development costs; however, building vessels without the need for crew facilities can introduce huge financial and environmental gains. Any move towards unmanned vessels will reduce onboard crew costs. In addition, without crew onboard, there is increased flexibility in terms of voyage journey times. This presents opportunities for new business models to be developed. Previous evaluation of various options for sustainable optimization to minimize fuel consumption and costs concluded that speed reduction or “slow steaming” was the most favorable strategy, with potential fuel savings of up to 15% (Cariou, 2011; Armstrong, 2013). Without a crew onboard, journey times can be extended and have greater adaptability to market demands. The anticipated energy savings will have a direct effect on reducing overall fuel consumption and therefore reducing exhaust gas emissions. The 2019 The United Nations Conference on Trade and Development (UNCTAD) Review of maritime transport estimates a world seagoing merchant fleet of 92,295 vessels. Maritime transport is essential to global trade and the manufacturing supply chains, with over 80% of world merchandise trade by volume carried by sea (UNCTAD, 2019).

In support of the United Nations 17 Sustainable Development Goals, and in particular goal 13 “climate action (UN, 2020), the International Maritime Organization (IMO) greenhouse gases (CHG) strategy has been developed with the aim of reducing overall carbon intensity from international shipping. The target sets out a reduction total annual GHG emissions from international shipping should be at least 50% by 2050 compared to 2008 (IMO, 2019b). The chart in Figure 1 (IMO, 2019b) illustrates the overall GHG reduction pathway to achieve IMO’s ambitious goals. In addition to the uptake of alternative low-carbon and zero carbon fuels, the potential innovation of remote/autonomous vessels is likely to make an essential contribution to emission reductions.

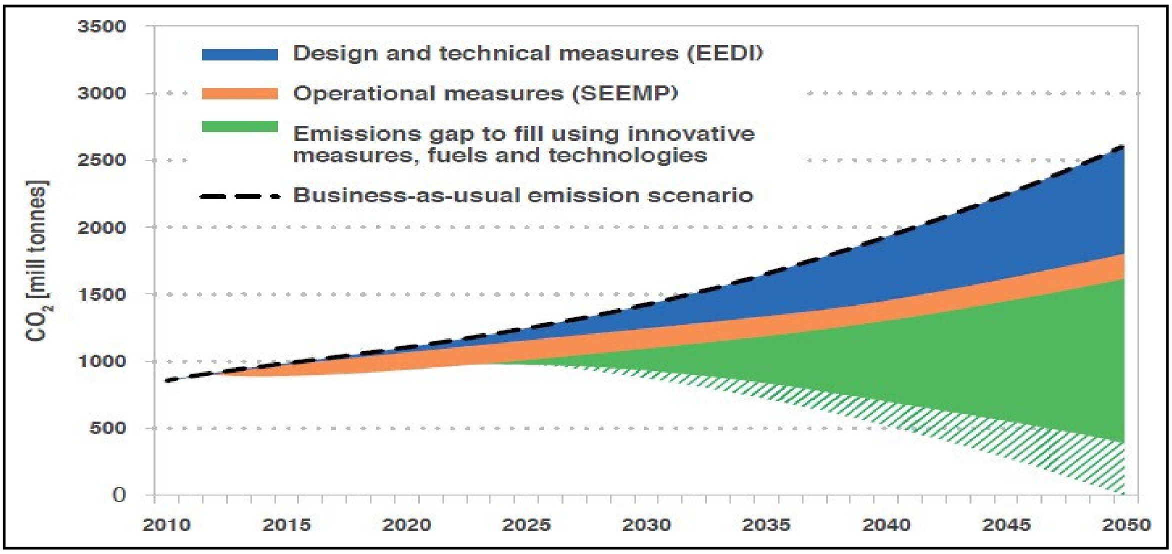


Figure 1 IMO 2050 Greenhouse Gas Reduction Pathway

1.2 Maritime Communications Background

In general, ships are increasingly dependent on systems that rely on digitization and integration which rely on communication links. Standardized and reliable ship-to-ship and ship-to-shore communication is essential for the safe operation of all vessels. For future autonomous and semi-autonomous vessels, the requirement for dependable communication systems is essential, as the functioning of such vessels will rely on remote control and real time monitoring.

This growth in connectivity and data exchange will entail a corresponding increase communications burden on existing infrastructures and will require the development of new systems. These systems must be secure, with redundancy and alternative backup arrangements a major consideration to safeguard reliability. The evolution of new communication structures will necessitate developments and amendments to international legislation and regulations. This is essential to ensure coordination and interoperability between future and existing maritime communications systems. In addition, the incorporation of autonomous vessels into existing maritime operational environments will require changes to established communication practices and procedures to ensure safe maneuvering for all vessels (IMO, 2021a).

Given the worldwide operational nature of shipping, future regulatory developments must be coordinated at a global level to facilitate procedural and technical harmonization. It is long established that the best way to achieve standardization and improve safety at sea, is by developing international regulations that are followed by all shipping nations. The standards and regulations which cover international shipping and maritime communications are a combination of international treaties and conventions which countries are signatories to. The development of these international regulatory instruments is coordinated and facilitated at inter-governmental bodies. In relation to maritime communications regulatory development, IMO (IMO, 2021c) and the International Telecommunications Union (ITU) are the preeminent United Nations Specialized Agencies for coordinating these activities (ITU, 2018; UN, 2021).

1.3 Research Problem

For the implementation of autonomous vessel operations to be realized within international shipping, beyond national waters and restricted test areas, the necessary communications regulatory framework and standards must be in place. For example, systems and protocols for how autonomous vessels communicate ship-to-ship in traffic situations must be established, to ensure the safe, secure and efficient operation for all vessels and mariners. Communication between autonomous vessels and all other existing types of manned craft and established communications systems must be evaluated. Additionally, there is a need to determine how such vessels will communicate with shore side facilities.

Within international shipping, there are a number of proven mandatory communication systems that vessels are required to carry as part of the Global Maritime Distress and Safety System (GMDSS). Additionally, Automatic Identification System (AIS) and Long-Range Tracking and Identification (LRIT) are mandated requirements for the majority of commercial vessels. These systems provide an aid to navigation in the identification, tracking and monitoring of vessel movements and for vessel tracking by shore side vessel tracking services (VTS). The requirements for autonomous vessel interaction and participation within these proven established systems must be considered and where necessary, amendments to existing requirements to address future needs must be developed.

In addition to mandatory systems, there are multiple commercial satellite services available which are in use onboard vessels. Interfacing with these established infrastructures and backwards compatibility must be considered in order for autonomous/remotely monitored vessels to operate safely. The legal framework and procedures of how autonomous vessels will operate within these existing and future communications structures does not currently exist and requires analysis. The IMO has completed a regulatory scoping exercise involving an initial assessment of regulations to determine their applicability to autonomous vessels and to establish if these regulations preclude autonomous vessel operations.

It is likely that real time monitoring and remote control of ships will be offered as potential solution to issues that may be identified as part of regulatory development. Therefore, scrutiny of maritime communication regulations will be required in order to progress the facilitation of autonomous/remote vessel operation. It is vital that the above challenges are addressed if these vessels are to be permitted to trade globally or between different jurisdictions. In addition to the ship/marine specific regulatory development work within the IMO, the ITU, which is the United Nations specialized agency responsible for information and communication technologies has a key role in determining technical characteristics and procedures of maritime communications systems.

In addition, the ITU has a vital role in the management of the world-wide radio-frequency spectrum. Radio spectrum is the essential resource which underpins all wireless communications. However, spectrum is a finite resource, therefore its allocation requires effective and efficient coordination at global level. This is achieved through the radio regulations which are necessary to ensure an efficient and economical use of the radio-frequency spectrum by all communications systems. It is the role of the ITU to promote, coordinate, and harmonize the efforts of its members states to fulfil these objectives (Pelton et al., 2012).

The communication frequency and bandwidth requirements along with associated procedures of any proposed future technologies and how this will impact on established systems and radio spectrum allocations must be assessed. The allocation of radio spectrum assigned to the maritime sector is limited. The ITU allocates global radio spectrum and satellite orbits. It also develops the technical standards that enable networks and technologies to interconnect. It is essential in the evaluation of autonomous vessel communication solutions for these factors to be adequately considered and researched.

1.4 Key Research Questions

The following questions require research, so that the communications regulatory framework challenges facing future autonomous vessel operations can be better understood.

- What are the existing mandatory ship communications systems, and will autonomous vessels interact with these?
- Can the potential communications requirements for autonomous vessels be accommodated within the existing maritime communications systems and regulations?
- Considering previous international rules development, what is the potential timeline for necessary regulatory changes to accommodate autonomous/remote vessels?
- What are the views of maritime industry and maritime communications experts in relation to the implementation of autonomous/remote vessels?

1.5 Research Scope and Objectives

The purpose of this analysis is to investigate and address the key research questions outlined. The study will attempt to identify the main technical regulatory issues relating to autonomous/remote vessel communication systems. Extensive secondary research and an in-depth literature review will be undertaken to study and examine potential autonomous vessel communication requirements and how existing systems, both mandatory and other potentially available technologies may be utilized or modified to provide the reliable connectivity. The research will attempt to recognize potential regulatory barriers and establish the route to making any required changes or amendments to international regulations.

A wide-ranging review of the overall basis of maritime communications legal structures, focusing primarily on shipboard requirements will be undertaken. Due to the international dynamics of both the shipping industry and communications, particular emphasis will be placed on international regulatory requirements rather than individual national legislation.

In addition to the literature review, empirical research will be carried out based on research questions which will be posed to maritime industry and maritime communication industry experts. The aim of these questions will be to ascertain the broad views of relevant influential specialists in order to gauge what they perceive to be the regulatory challenges and what timescale they believe is required for necessary international regulations to be implemented. This research will provide a beneficial insight into what may be considered as realistic in terms of a regulatory timescale.

2 Literature Review

To fully understand and accurately assess the potential communications regulatory requirements which may apply to future autonomous and remotely operating vessels, a comprehensive review of established mandatory maritime safety communications and other mandatory systems has been undertaken. This research is considered essential, as there will be a need for future vessels to interact and communicate with existing vessels in the maritime environment. In addition, a review of the potential data requirements and available commercial communications technologies has been carried out. The review of the associated regulatory frameworks and timelines has also been undertaken. The results of this review have been used to formulate a comprehensive expert survey.

2.1 Literature Review Scope

To be able to fully determine potential communication requirements this literature review covers the following topics:

- overview of established mandatory maritime communications systems;
- review of potential ship data sources for autonomous/remote vessel operation;
- review of established commercially available maritime communications systems;
- appraisal of related regulatory environment.

2.2 Review of Existing Mandatory Maritime Communications Systems

This review focusses on the existing mandatory communications requirements for internationally trading ships. These include safety communication systems, safety of navigation, ship monitoring and security systems. This research provides a clearer understanding of the potential mandatory communications requirements for autonomous and remotely monitored vessels. In addition it considers systems which such vessels will have to integrate with to facilitate safe intergradation into areas where manned vessels will continue to operate.

2.3 Global Maritime Distress and Safety System (GMDSS)

Fully implemented on the 1st of February 1999, the Global Maritime Distress and Safety System (GMDSS) is the standard international safety communication system relied upon by vessels at sea. The GMDSS is made up of terrestrial and satellite technology and shipboard radiocommunication systems. The fundamental concept of the GMDSS is to provide ships with the reliable means to raise a distress alert to shore-side search and rescue authorities and to vessels in the vicinity, in the event of an emergency where assistance is required. Using the various communication systems within the GMDSS, ships have the ability to communicate with and automatically alert coast rescue authorities and nearby vessels quickly using separate and independent means so that a coordinated search and rescue response can be actioned with minimal delay (IMO, 2019a).

The safety radiocommunication requirements for internationally trading ships apply to all vessels above 300 gross tonnage are set out in Chapter IV of the International Convention for the Safety of Life at Sea (SOLAS; IMO, 2014). These ships are required to carry and maintain specific types of radio equipment which are necessary to facilitate safety and distress related communications irrespective of the vessel's global area of operation. The equipment carriage requirements for vessels are determined by the sea area of operation, that is, the communication coverage area in which a vessel operates within, determines the mandatory radiocommunication equipment installation onboard.

The nine GMDSS functional requirements are set out in Chapter IV of SOLAS requires that every ship, while at sea, shall be capable of the following.

1. Ship-to-shore distress alerts by at least two separate and independent means, each using a different radiocommunication service.
2. Receiving shore-to-ship distress alerts.
3. Transmitting and receiving ship-to-ship distress alerts.
4. Transmitting and receiving search and rescue co-ordinating communications.
5. Transmitting and receiving on-scene communications.
6. Transmitting and receiving signals for locating.
7. Transmitting and receiving maritime safety information
8. Transmitting and receiving general radiocommunications to and from shore-based radio systems or networks and
9. Transmitting and receiving bridge-to-bridge communications.

Figure 2 (ITU, 2020a) shows a typical GMDSS installation on the navigational bridge of a ship and an example of float free emergency position-indicating radio beacon (EPIRB). EPIRBs are an essential piece of shipboard GMDSS equipment which provides a secondary means of alerting and automatic alert activation in the event that a vessel sinks before a manual distress can be activated. EPIRBs operate through the Cospas-Sarsat satellite system which is designed to provide distress alert and location data to assist in search and rescue authorities. The Cospas-Sarsat system comprises of satellite and ground facilities to detect and locate signals of distress beacons operating in the frequency band 406.0-406.1 MHz (Cospas-Sarsat, 2020).

Figure 2 Ship Bridge GMDSS Installation and Float Free EPIRB

Figure 3 (ITU, 2020a) is an example of the typical shore-side coast radio station infrastructure and with GMDSS facilities and an example of a maritime search and rescue coordination center.

Figure 3 Typical Shore-side GMDSS Infrastructure and Rescue Coordination Facilities

The shipboard carriage and operator requirements for maritime radiocommunications for internationally trading ships is set out within Chapter IV of the IMO SOLAS Convention and are currently defined under the four sea areas A1 to A4. Within each of the classified sea areas of operation, vessels must have the ability to initiate distress alerts via two separate and independent means of communication.

A1 - An area within the radiotelephone coverage of at least one very high frequency (VHF) coast station in which continuous digital selective calling (DSC) alerting is available. Typically, 20 – 30 nautical miles from a coast station, that is, VHF line-of-sight range.

A2 - An area, beyond sea area A1, within the radiotelephone coverage of at least one medium frequency (MF) coast station in which continuous DSC alerting is available. Typical approximation, 100 – up to 400 nautical miles offshore.

A3 - An area, beyond sea areas A1 and A2, within the coverage of an Inmarsat geostationary satellite in which continuous alerting is available. Considering the Inmarsat coverage footprints, this area is conservatively considered as approximately between the latitudes 76° north and 76° south.

A4 - An area outside sea areas A1, A2 and A3. This is essentially the polar regions, north and south of approximately, above/below 76° of latitude, that is, distress altering, and communication relies on high frequency (HF) DSC and radiotelephony.

Figure 4 (IMO, 2019a) illustrates the overall system concept and the various interdependent shoreside facilities that make up the GMDSS. The functioning of each of these components that make up GMDSS, ensure that every ship, irrespective of their area of operation, can perform the essential communication functions which are critical for the safety of the ship itself and of other vessel operating in the same area, therefore the GMDSS is essential for global vessel safety.

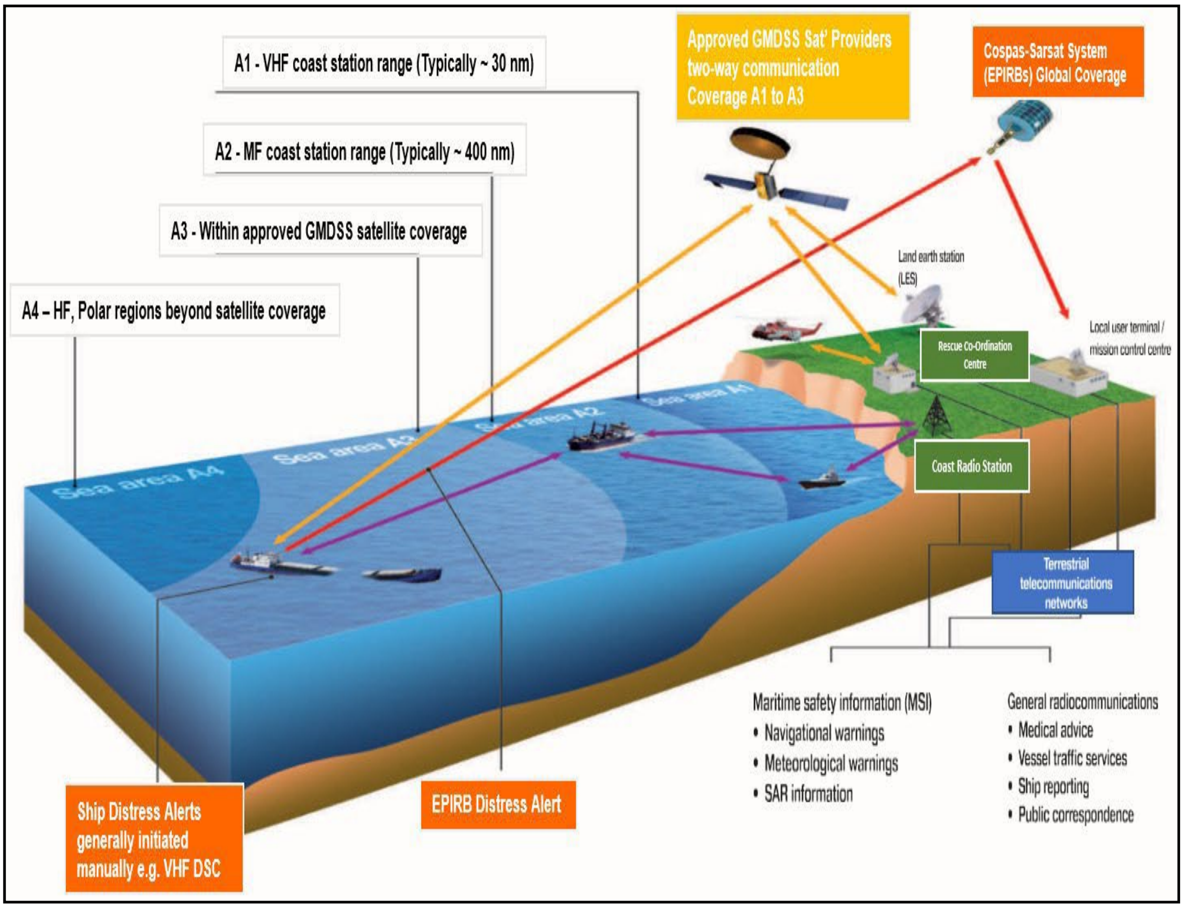


Figure 4 GMDSS Basic Concept Overview

In addition to providing vessels with the means to initiate a distress alert, the GMDSS also provides for the distribution of urgency and safety communications and for the promulgation of maritime safety information (MSI), including navigational and meteorological warnings and forecasts and other urgent safety information to ships (IMO, 2019a).

The primary systems used for the broadcast of maritime safety information is the MF terrestrial NAVTEX system. NAVTEX broadcasts are coordinated and made by coast radio stations and had an effective coverage of approximately 200 nautical miles from the shore station.

Satellite MSI distribution is provided by the two approved GMDSS satellite providers, Inmarsat and Iridium. The Inmarsat SafetyNET is the service for broadcasting and automatic reception of Maritime Safety Information via Enhanced Group Call (EGC), with a coverage up to and including sea area A3. The alternative Iridium SafetyCast is an enhanced group call service for the promulgation of MSI with global coverage including polar regions. High frequency narrow-band direct printing telegraphy (NBDP) may also be used to promulgate maritime safety information in areas beyond the SafetyNET and NAVTEX coverage areas, including sea area A4 polar regions. Maritime safety information may also be broadcasted on voice radiotelephony (ITU, 2020a).

Figure 5 (ITU, 2016) provides examples of the typical shipboard equipment used within the GMDSS for the reception of maritime safety information broadcasts. The required MSI reception equipment is dependent on the vessels area of operation, that is, MSI broadcast coverage area.

Figure 5 Shipboard Equipment for Reception of Maritime Safety Information

It is estimated that over 100,000 large commercial merchant ships and millions of other vessels use the communication facilities and procedures established under GMDSS, with the predominant usage in terrestrial VHF communications (Jennings, 2016). In addition to internationally trading vessels which are covered under the requirements of SOLAS, vessels not subject to international mandatory requirements, have also extensively adopted the GMDSS. For example, Fishing vessels, smaller passenger vessels and pleasure vessels routinely participate in the GMDSS and rely on it for General and Distress related communications. These vessels often install GMDSS equipment on a voluntary basis, or, to meet requirements which may be set out under the national legislation. In many countries, the majority of commercial vessels which operate in domestic coastal waters, that is, not on international voyages, are required to fulfil some, or all aspects of the GMDSS functions.

Figure 6 Fishing and Pleasure Vessels Use of GMDSS

Commercial fishing vessels are encouraged to be fitted with equipment to enable their participation in GMDSS under the Cape Town Agreement of 2012 implementing the Protocol of 1993 relating to the Torremolinos International Convention for the Safety of Fishing Vessels (IMO, 2015). This international instrument closely aligns simplified fishing vessel GMDSS carriage requirements with those of chapter IV of SOLAS (IMO, 2012). For many countries, vessel radiocommunication requirements are already prescribed under domestic legislation.

Vessels which are not required to comply with the 1974 SOLAS Convention e.g., yachts, are recommended to comply with the guidelines for the participation of non-Convention ships in the GMDSS outlined in MSC/Circ.803 (IMO, 1997). Such ships are recommended to carry basic GMDSS equipment appropriate to their area of operation.

2.4 GMDSS Personnel Requirements

Regulation 16 of Chapter IV of the SOLAS convention applies to all vessels over 300 gross tonnes. Chapter IV mandates that all ships must have suitably qualified personnel on board to perform distress and safety radiocommunication functions. SOLAS Chapter IV

Regulation 3 does provide for administrations to grant partial or conditional exemptions in exceptional circumstances to individual ships from the radio equipment requirements of SOLAS. However, it is noted within the regulation that such deviations from the requirements are considered highly undesirable (IMO, 2020b).

Significantly for autonomous vessels operations, Regulation 3 does not provide for administrations to exempt vessels from the radio personnel requirements. These radiocommunications personnel must hold a certificate specified in the ITU Radio Regulations (ITU, 2020b). Under Article 46.1 of Radio Regulations, the master or person responsible for the ship/vessel and is required to ensure that the radiocommunications is operated in accordance with ITU Radio Regulations at all times.

In addition, SOLAS Regulation 3 does not provide for administrations to exempt vessels from the watchkeeping requirements which mandate that every ship, while at sea, shall maintain a continuous watch on appropriate GMDSS frequencies. Both the equipment performance standards and maintenance requirements can also not be provided with exemptions.

As there is no facility to exempt vessels from the personnel requirements, the provisions of IMO SOLAS Chapter IV and the ITU Radio Regulations therefore, mandate that there must always be human surveillance of the radiocommunications systems for vessels which SOLAS applies to. Any amendment to the above fundamental requirements would require significant coordination and regulatory agreement between the member states of the IMO and the ITU.

2.5 Additional Mandatory Maritime Communication Systems

In addition to the GMDSS technologies and procedures, which are relied upon by the shipping industry and wider maritime community for safety and general communications between vessels and from vessels to shore, there are number of additional mandatory systems which enhance the safety of navigation, vessel monitoring and ship security. These systems, which are summarized below, will likely be mandatory requirements and essential to supporting autonomous vessel operations.

2.4.1 Automatic Identification System (AIS)

The Automatic Identification System (AIS) was developed to provide automatic information exchange between ships and from ships to shore. The AIS system is based upon an international open technical communication standard (ITU, 2014). AIS transceivers operate autonomously, without the need for interaction by ship or shore personnel on two dedicated channels, transmitting frequencies in the VHF maritime mobile band. The AIS channels may also transmit from ships to satellites, this facility is utilized by commercial providers for the provision of long-range tracking of vessels equipped with AIS (ITU, 2020b). The implementation of AIS has contributed to the safety of navigation and facilitates more efficient vessel traffic management. By continuously exchanging data such as vessel identity, dimensions, and dynamic information such as position from an internal or external Global Navigation Satellite System (GNSS) receiver e.g. Global Positioning System (GPS), speed, course, and overall navigational situational awareness for vessels is enhanced (IALA, 2016). AIS is mandated as a shipboard carriage requirement for vessels under SOLAS Chapter V “Safety of navigation” (IMO, 2014). In addition, AIS is required domestic commercial vessels by many administrations under national legislation. Like the GMDSS, AIS has also been extensively adopted by vessels which are not subject to mandatory requirements. Figure 7 (IALA, 2016) shows a typical ships bridge navigation display including AIS target data.

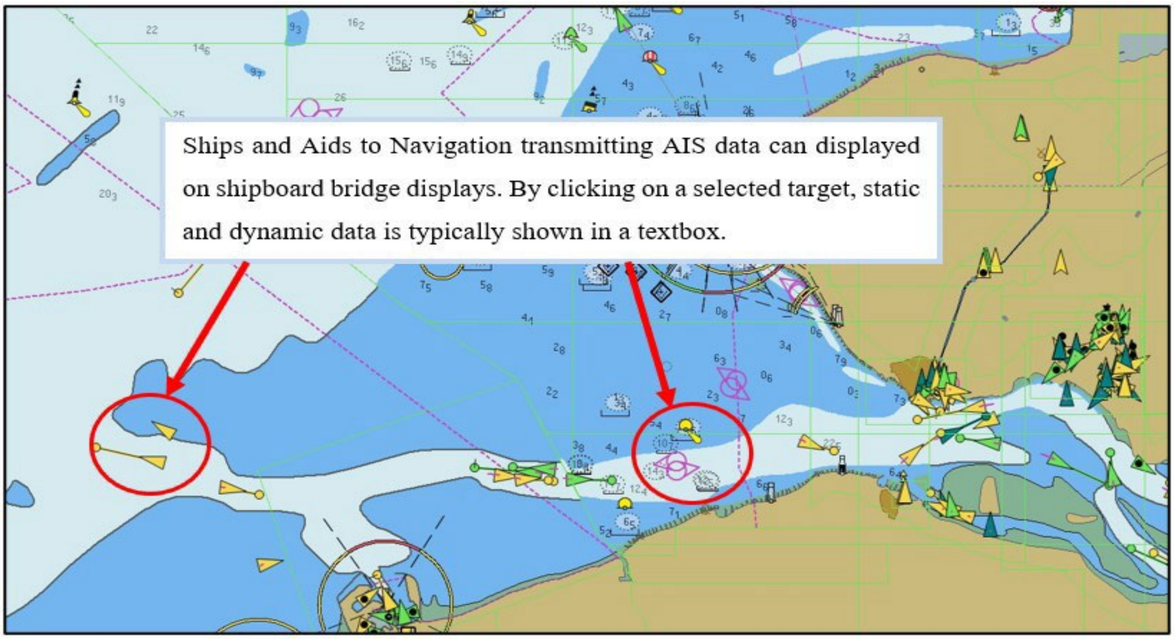


Figure 7 Typical AIS Display

2.4.2 Long-Range Identification and Tracking of Ships (LRIT)

In addition to AIS, the Long-Range Identification and Tracking system (LRIT) is a requirement under Chapter V of SOLAS which applies to ships constructed after 31 December 2008 with a phased implementation period for existing ships. The main purpose of LRIT is to improve maritime security, safety, and environment protection. LRIT reports are required to be transmitted every six hours form vessels to a shoreside LRIT Data Centre via satellite. The frequency of LRIT transmission is controlled remotely, therefore vessel report polling can be increased if additional vessel monitoring is required. Reporting can be increased up to a rate of one report every 15 minutes. Ships are required to transmit vessel details, position and date/time to contracting governments and administrations via the LRIT system (IMO, 2014). The International Mobile Satellite Organization (IMSO) is organization with the oversight and coordination mandate for the LRIT system.

In contrast to AIS, which is an open VHF broadcast system, LRIT data is only available to governments and/or national administrations. Administrations are eligible to receive information about ships navigating within a distance up to 1,000 nautical miles from their coast, or information from ships which indicate that they intend enter a port of the administration, irrespective of distance. Administrations are also permitted to receive information about their own vessels at any time (IMO, 2019a). Although LRIT is not a part of the GMDSS equipment requirements, satellite terminals installed for GMDSS are utilized to provide LRIT the necessary reports from vessels to shore.

2.4.3 Ship Security Alert Systems (SSAS)

The Ship Security Alert Systems (SSAS) is required under SOLAS Chapter XI-2.6. The system is used by ships to transmit a security alert via satellite link to a designated shoreside authority/contact in the event that the security of the ship is compromised or may be under threat (IMO, 2020b). Like LRIT, SSAS alerts are sent via GMDSS Inmarsat C terminals. In contrast to GMDSS distress alerts, which is designed to be received by all possible shore and ship stations within the area, the SSAS is intended to be activated covertly. For security purposes, alerts are transmitted to the competent authority ashore with no alarm raised on board the ship nor alert transmitted to other ships (IMO, 2019a).

2.4.4 Global Navigation Satellite System (GNSS) Receivers

GNSS systems are relied upon by vessels for navigation by providing of precise position fixes worldwide. GNSS provides real-time position information on board ships to an accuracy of meters (ITU, 2017). As per SOLAS Chapter IV "Radiocommunications", regulation 6.4, the ship's position information should be continuously and automatically provided to all relevant radiocommunication equipment (IMO, 2014). In the event the event of a distress alert being initiated from GMDSS equipment, the GNSS position is automatically broadcast as part of the alert.

The operation of all autonomous and remotely operated vessels will be completely reliant on the functioning of GNSS receivers to provide accurate positioning. However, GNSS receivers are vulnerable to interference. Jamming is predominant source of interference, with the overloading of signals on relevant frequencies used to prevent the GNSS receiver from utilizing the authentic signal. In addition, spoofing, which is more sophisticated method of interference is also possible and involves the broadcast of incorrect signals so that vessel GNSS receivers track the false signal and obtain incorrect position information (NATO, 2021).

Due these vulnerabilities and the reliance on GNSS, additional redundancy measures to ensure availability and reliance to potential disruptions is essential. This may necessitate enhanced anti-spoofing and ant-jamming receivers to provide greater resilience. In addition, power supply and redundant fallback GNSS receivers may be desirable (Glomsvoll and Bonenberg, 2017).

2.5 Interaction with Existing Mandatory Communication Systems

In order for autonomous/remotely monitored vessels to safely operate within the same areas as crewed vessels, it is highly likely that such vessels will be required to comply with the radiocommunications requirements for existing vessels. For example, for vessel tracking and monitoring, and for safety of navigation, autonomous/remote vessels will require to integrate with and transmit information on AIS. For security purposes, LRIT is also likely to remain a requirement.

Certain aspects to the GMDSS are likely to be mandatory for autonomous/remote vessels, when considering that even if such vessels may not have crew onboard, they may be tasked with assist other vessels in distress. This can include acting as a communications relay link from vessels in distress to shore search and rescue authorities.

In order to carry out the manual functions of the GMDSS, such as voice communications, reliable remote links to control onboard GMDSS equipment would be necessary. The majority of current commercial vessels rely heavily on GNSS systems for navigation and operation, this reliance will be even higher for unmanned vessels, where establishing a vessel's position using traditional visual means may not be practicable.

The potential utilization or any requirements of future autonomous vessels in relation to existing mandatory systems will require careful consideration within the relevant international regulatory frameworks, as current procedures and standards were developed on the basis that vessels would be adequately crewed. An example of one such set of procedures which may require revision to consider future autonomous vessels is Article 32 of the Radio Regulations, which contains the operational procedures for distress communications in the GMDSS (ITU, 2020b). The introduction of autonomous vessels may also require the updating of maritime training syllabi, so that seafarers onboard conventional vessels are adequately trained and aware of any new procedures regarding interaction with such future vessels.

Considering the above, additional system redundancy measures will likely be required, as there will be reduced, or no crew onboard to resolve technical issues as they inevitably arise. Table 1 (IMO, 2020b) provides a summary of current GMDSS and mandatory communications equipment and potential future functionality in terms of autonomous/remotely operated vessels.

Table 1 GMDSS and Mandatory Communications Equipment Potential Autonomous Functionality

Equipment	Current Function	Range	Applicability to Autonomous/Remote Vessel
VHF with DSC	General and Distress Analogue Voice Communication. DSC Distress Alerting	Approximately 30 miles	Likely to be required for Autonomous/Remote Operations for Vessel-to-Vessel and Vessel-to-Shore voice and DSC communications via remote link and distress altering/reception
MF telephony with MF DSC	General and Distress Analogue Voice Communication. DSC Distress Alerting	Medium-range Approximately 400 miles	Not likely to be required for Autonomous/Remote Operations. Beyond terrestrial communication services, future vessels will likely rely on satellite connections
GMDSS Inmarsat satellite or Iridium satellite	Satellite distress alerting, MSI reception	Global (depending on provider)	Likely to be required for Autonomous/Remote Operations, distress altering/reception, MSI reception, potential general communications
NAVTEX receiver 518 kHz	Reception of Maritime Safety Information from Shore Stations	Medium-range Approximately 200-400 miles	Not likely to be required for Autonomous/Remote Operations as it may be possible to receive relevant NAVTEX broadcast information within a remote monitoring centre from alternative sources e.g., via the internet
Float-free satellite EPIRB	Distress alerting through the Cospas-Sarsat satellite system	Global	Possibly required for Autonomous/Remote Operations for distress altering in the event of vessel sinking
Radar transponder (SART)	Search and Rescue Locating Using 9GHz Radar Homing Signal	Radar range.	Not likely to be required for Autonomous/Remote Operations
AIS Search and Rescue Transmitter	Search and Rescue Transmitter for Locating using AIS technologies	Lees than 30 miles	Possibly required for Autonomous/Remote Operations for distress locating supported by remote activation
GNSS Receiver	The provision of vessel position /location and vessel navigation.	Global	Essential for all Autonomous/Remote Operations to provide vessel position information
AIS	Vessel identification, traffic management, vessel monitoring, safety of navigation	Approximately 30 miles with possible satellite tracking capability	Essential for all Autonomous/Remote Operations to facilitate safe navigation, vessel monitoring and situational awareness for all AIS equipped vessels in the area of operation
LRIT	Vessel identification, monitoring, and security	Global	Likely to be required for Autonomous/Remote Operations for long range vessel monitoring and to meet port security and reporting requirements
SSAS	Vessel security alert system	Global	Not likely to be required for Autonomous/Remote Operations if vessel is unmanned

2.6 Overview of Ship Data Sources Requirements

To assess the communications requirement of future autonomous/remotely vessels, it is necessary to consider the data that is currently generated and monitored on-board vessels. In addition to existing data, sensor information deployed as part of autonomous solutions will create a significant additional data burden which will be require robust communication to/from any remote monitoring and control shore stations. Table 2 (DNV, 2018) below is a non-exhaustive list of functions associated with a conventional ship that may be subject to a high level of automation and remote monitoring and control.

Table 2 List of Monitored Data Sources Associated with a Conventional Ship

Navigation Functions	Engineering Functions	Other Vessel Functions	Special Operations
— Voyage/ Route planning — Determination of position, course, and speed — Follow route — Maintaining general lookout — Determine CPA and TCPA of potential obstacles and other ships — Monitoring depth, sea-state, current, weather/visibility — Monitor seakeeping performance — Monitor for, and react to, distress signals from other seafarers (GMDSS) — Docking/Undocking — Maneuvering — Propulsion control — Steering — Grounding and collision avoidance — Weather routing — Communication with other vessels — Communication with shore (vessel traffic service, rescue services, pilot services, etc.) — Navigation lights and sound signals — Overall supervision of bridge-related systems — Overall condition supervision	— Overall supervision of machinery-related systems — Machinery control and monitoring — Electrical Power generation and distribution — Fuel optimization — Emission control and monitoring — Fuel management — Battery charging control and monitoring — Maintenance planning	— Monitoring of cargo and cargo operations — Shell-door control and monitoring — Watertight doors control and monitoring — Stability/ballast control and monitoring — Ballast water control and monitoring — Bilge and drainage control and monitoring — HVAC control and monitoring — Freshwater control and monitoring — Anchoring — Mooring — Unmooring — Fire detection — Fire fighting — Logging of data and events	— Position keeping (dynamic positioning) — Seabed mapping — Firefighting — Rescue op's — Damage control

In addition to the existing monitoring required by a conventional system in Table 2, the potential additional data and feedback information required for remote vessel monitoring, will be significant e.g., video and sensor data (DNV, 2018). Table 3 (Höyhtyä, Huusko, Kiviranta, Solberg, & Rokka, 2017) provides a summarized estimation of amount of data to be transferred for remote operations and autonomous monitoring. However, in considering existing monitoring requirements this may be considered as a low estimation of data transfer requirements, above, the practical data burden will possibly be greater for continuous overall vessel monitoring.

Table 3 Remote Monitoring Data Requirements

System	Single file/Image (kB)	Update rate (Hz)	Compressed bit rate (kbps)
Radar/AIS	375	0.4	100
Video	200 - 500	1-10	150-1500
HD video	2600	2	800-1500
LiDAR	Up to 200 000	1	1000-2000
Infrared	330	1-10	300-1000
Mechanical sensors	12	0.1-1	1-10
Control data	Varies	1	1-10
General GMDSS data	Varies	As required (Alerting or remote communication data)	10

The largest estimated data transfer requirement in Table 3 for remote monitoring is the ship is sensor information. Such sensor information includes systems for the provision of remote situational awareness such as onboard infrared cameras, LiDAR, radar, and optical cameras. The ship operational systems e.g., engine room monitoring, and sensors related to propulsion and maneuvering systems will remain critical. The need for increased reliability of these shipboard essential systems will likely increase the data transfer requirement to the remote operation centers above that of existing onboard monitoring (Höyhtyä et al., 2017).

2.7 Consideration of Existing Maritime Communications Systems

Previous research has indicated that the communication systems for full remote-control operations from shore should for be capable of at least 4 Megabits/second. However, this data requirement may be lowered to 125 kilobits/second for reduced operations. If a vessel can operate in a fully autonomous mode, then the required communication bandwidth may also be reduced Cost and availability of communication is an issue (Rødseth et al., 2013). Considering that Table 3 outlines an estimated compressed data requirement of 6 Mbps, the potential data burden required for autonomous operations is currently beyond the bandwidth available to maritime services, with the capacity of the GMDSS and associated communication systems insufficient and limited to existing safety functions. This deficit in terms of available and required communications facilities is a major technical hurdle which must be considered in terms of autonomous/remote vessel operations.

At present, there are no dedicated safety specific communications systems to meet requirements for the operation or remote monitoring of proposed autonomous vessels. The availability and use of frequency bands used within the maritime and satellite services are set out in the ITU Radio Regulations (RR) e.g., the frequencies for the GMDSS are provided for under RR Article 31 and are contained within Appendix 15 of the RR (ITU, 2020c). The radiocommunications spectrum is a finite resource which is under ever increasing demand from commercial interests and users globally, such as the mobile phone sector. This means that even if there is a requirement for additional capacity for maritime operations, it simply is not available.

Within the existing maritime frequency provisions, there may be scope to obtain data efficiencies through a transition from analogue to digital communications. However, such transitions are likely to be long term, as existing users, system compatibility and costs of implementation must be factor in.

Table 4 (IALA, 2017) below, details the various communication technologies available. The key issue is the existing maritime GMDSS approved satellite systems provide have an estimated data limit of 134 kbps is circa 2% of the potential requirement. Alternatively, public terrestrial systems, such as mobile phone networks e.g., 4G and 5G have ample data capacity, however, these networks are limited to near coastal coverage. In addition, these public networks do not have the same required reliability as existing maritime safety communication systems.

Table 4 Available Data Communications Technologies

Communication Technology	Data rate limit	Coverage	Infrastructure	Transmission	Maritime / Public
WiMax	75 Mbps	2-5 km	Routers/Access points	Addressed	Public
5G	1,200 Mbps	(3-6 nautical miles from shore)	5G base stations	Addressed	Public
4G	600 Mbps	(3-6 nautical miles from shore)	5G base stations	Addressed	Public
Wi-Fi (IEEE 802.11ac)	1,300 kbps	50m	Routers/Access Points	Addressed/Broadcast	Public
Inmarsat C	600 bps	Global (Limited to Sea Area A3)	Geostationary GMDSS Satellite Constellation	Addressed/Broadcast	Maritime
Inmarsat C Global Express	50 Mbps	Global, Spot Beams	Geostationary Satellite Constellation	Addressed / Broadcast	Multi Industry
Iridium	134 kbps	Global	Low Earth Orbit Satellite Constellation	Addressed / Broadcast	Multi Industry

2.5 Overview of Maritime Communications Regulatory Environment

The IMO is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. It is the global standard-setting authority for the safety, security, and environmental performance of international shipping. It provides a regulatory framework for the shipping industry, including the safety related requirements for internationally trading ships (IMO, 2021c). The radiocommunication requirements for internationally trading ships are set out in Chapter IV of the IMO's SLOAS Convention (IMO, 2014).

The ITU is the United Nations specialized agency for information and communication technologies (ICTs). Founded in 1865 to facilitate international connectivity in communications networks, ITU's global membership includes 193 Member States (ITU, 2018). Supported by international treaties and agreements, the ITU coordinates global radio spectrum, satellite orbits and develops technical standards that ensure networks and technologies seamlessly interconnect. Standardized, reliable maritime communication is essential for the safe operation of all vessel types worldwide (ITU, 2018)

The systems which seafarers rely upon for communication and day-to-day operation, such as VHF, AIS, MF/HF, satellite networks, etc. are all facilitated through the work of the ITU and are covered under the provisions of the Radio Regulations and associated standards contained within the various ITU technical recommendations and reports (ITU, 2022b). In addition, the ITU manages the assignment and use of maritime identities and plays a key role in operational safety through its maritime service publications. The publications contain important technical and operational information for the maritime industry in relation to radiocommunications.

The GMDSS and other maritime radiocommunication systems are underpinned by the Radio Regulations and the related ITU Recommendations and Reports. For example, the allocated frequency bands to be used for distress and safety information under the GMDSS are contained in Appendix 15 of Article 31of the Radio Regulations, with the operational procedures contained in Article 32 (ITU, 2020b). In addition to the significant roles of the ITU and IMO in relation to international maritime communications regulatory development, IMSO, as the organization with oversight over GMDSS satellite providers, may have a significant role in terms of the approval of any future satellite provision to meet the high data requirements of future autonomous or remote operations.

2.8 International Maritime Communication Regulatory Developments

Work on the modernization of the GMDSS has been underway for over ten years (IMO, 2021b). The IMO has now adopted amendments to the Safety of Life at Sea Convention Chapters III and IV and the necessary consequential revisions to other existing instruments. This involved an extensive scope of regulatory work with multiple resolutions, standards and circulars requiring amendment.

The results of this modernization work include the consolidation of the requirements for safety communication equipment will be included in one chapter of SOLAS, this is largely an editorial outcome. Significantly, the Iridium satellite system has been recognized by the IMO as a mobile satellite service for the GMDSS. Additionally, China's BeiDou satellite system has applied for recognition and is under consideration by the IMO. New performance standards for float-free EPIRBs operating on 406 MHz will be introduced.

The definition of systems providing Maritime Safety Information (MSI) will be replaced by a more general definition to provide flexibility in the systems which can be utilized to fulfil vessel MSI requirements. This includes the option to utilize a new digital system, NAVDAT, which is an MSI broadcast system from shore stations to ships (Bauk, 2019). The definition of the sea area A3 will change and vary depending on the type of mobile satellite service installed on the vessel, as the Iridium system no provides global satellite coverage. As per the GMDSS Modernization timeline illustrated in Figure 8, the final approval and/or adoption is expected at the IMO’s Maritime Safety Committee which is due to be held in April 2022. These amendments are expected to enter into force in 2024.

Figure 8 GMDSS Modernization IMO Timeline

In parallel to work on the modernization of the GMDSS within the IMO structures, regulatory work has been underway within the ITU to make the necessary amendments to the Radio Regulations and associated technical standards to facilitate updates to GMDSS provisions. This extensive and detailed process is carried out by experts representing national administrations within the ITU's Study Groups. Figure illustrates the Modernization Timeline for the GMDSS within the ITU.

The ITU provides the international forum for administrations to work together to ensure reliable and efficient maritime communication services globally. The focus of these Study Groups is to develop and agree improved standards and procedures which are established through technical recommendations. The work program of these groups follows the agenda items of the ITU World Radio Conference (WRC). The WRC takes place on a three to four year cycle, with adopted outcomes incorporated into the ITU Radio Regulations, which is the international treaty governing the use of the radio frequency spectrum and satellite orbits (Bogens, 2017). These regulations contain important provisions related to maritime distress, urgency, and safety communications, as well as requirements on professional knowledge, qualifications for ship's radio personnel and documentation carriage requirements.

The harmonized approach to development coordinated by the ITU, contributes to the protection of existing systems such as distress and safety of navigation systems from harmful interference or misuse of frequencies. The modernization of GMDSS and implementation of e-navigation are on the agenda for the forthcoming WRC-23, with work already underway in the relevant ITU Study Groups (ITU, 2022a). The further development of maritime radiocommunication standards can enable improved systems and services, that will ultimately benefit the maritime industry and potentially support the implementation of autonomous/remote operations.

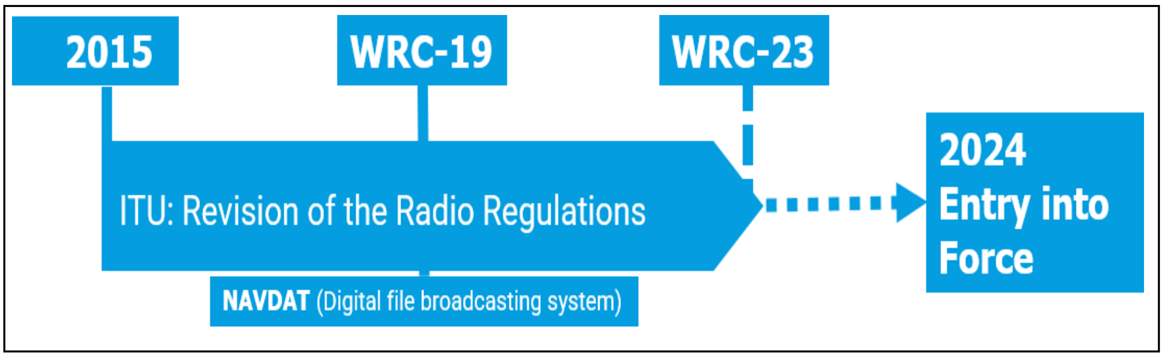


Figure 9 GMDSS Modernization ITU Timeline

2.9 Current ITU Maritime Communication Regulatory Developments

In preparation for WRC-23, three maritime topics are currently under consideration. These topics are, GMDSS modernization; E-navigation; and the introduction of an additional satellite system into the GMDSS. These studies include the completion of necessary provisions for the full incorporation of the NAVDAT digital file shoreside broadcasting system into the Radio Regulations as part of GMDSS modernization.

Noting that 1.6 GHz Emergency Position Indicating Radio Beacons (EPIRBs) are no longer in use, it is proposed to modify the radio regulations, so that the use of this frequency band is no longer limited exclusively for use by EPIRBs. The intention is to make this band available for use within the GMDSS, and for general maritime radiocommunications by providing additional capacity in the Earth-to-space direction for communications by ships. This may provide some additional data capacity for future autonomous/remote operations, however, like the current Inmarsat GMDSS satellite system, capacity may be low.

Support of e-Navigation concept is also on the agenda for WRC-23 and currently under study. E-Navigation is an International Maritime Organization (IMO) led concept based on the harmonization of marine navigation systems and supporting shore. The definition of e-Navigation as adopted by IMO is, “e-navigation is the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment.” It is recognized that communication is a key element for e-navigation. As the e-navigation concept is expected to provide digital communications for the benefit of maritime industry, it may play a significant role in the implementation autonomous/remote vessel operations (IALA, 2018).

The current position for WRC-23 in relation e-Navigation are, the frequency bands for the VHF Data Exchange System (VDES) and NAVDAT exist and may support e-navigation. Satellite networks which could support e-navigation already have their allocation identified in the Radio Regulations (Bauk, 2019). Therefore, it is considered that no additional frequency allocation is necessary in for the e-navigation at present (ITU, 2021). The absence of progress in relation to e-navigation developments may limit the potential applicability of it for autonomous/remote operations in the near future.

2.10 Future ITU Maritime Communication Regulatory Developments

There are two maritime related items already included in the preliminary agenda for the 2027 ITU World Radiocommunication Conference. The first item is to consider improving the utilization of the VHF maritime frequencies band. The second item is to study and develop technical, operational, and regulatory measures to facilitate the use of the frequency bands 37.5-39.5 GHz (space-to-Earth), 40.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space) by aeronautical and maritime users (ITU, 2020b).

Both of these agenda items offer potential for developments which may be directly relevant to autonomous vessel communications. The possible improvement of the utilization of the VHF maritime frequencies band may facilitate autonomous vessel remote VHF voice communications or facilitate additional options for vessel monitoring in coastal areas using a digitized portion of the band. The development of technical, operational, and regulatory measures to facilitate the use of additional satellite frequency bands for maritime services also may also directly enhance the communication options available to autonomous or remotely monitored vessels.

2.11 Current IMO Maritime Communication Regulatory Developments

In May 2021, IMO’s Maritime Safety Committee (MSC) completed a regulatory scoping exercise to analyze relevant ship safety treaties, in to assess how Maritime Autonomous Surface Ships (MASS) could be regulated. The scoping exercise began in 2017 to determine how MASS operations might be addressed in IMO instruments. Varying degrees of autonomy were considered: crewed ship with automated processes and decision support (Degree One); remotely controlled ship with seafarers on board (Degree Two); remotely controlled ship without seafarers on board (Degree Three); and fully autonomous ship (Degree Four) (IMO, 2021a).

The scoping exercise assessed the applicability of various safety instruments to MASS. To determine of each regulatory provision could potentially be regulated by equivalences as provided for by the instruments or developing interpretations; and/or amending existing instruments; and/or developing a new instrument; or none of the above as a result of the analysis.

The outcome highlights high-priority issues, across several instruments, that must be addressed at a policy level to determine future work. MSC considered the potential best approach to address MASS in the IMO regulatory framework may be through the development of a goal-based standards with functional requirements and corresponding regulations. The MSC invited Member States to submit proposals on how to achieve the best way forward to a future session of the Committee (IMO, 2021a).

In terms of communications, the outcome of the scoping exercise notes that there are no existing specific requirements on remote monitoring and remote control in the instruments. To address this, specific requirements on remote monitoring and remote control may be developed e.g., requirements on Remote control center, including facility and manning, communication network and system, human machine interface. Significantly, these regulatory requirements would need separate development, in addition to the work of shipboard requirements.

Table 5 (IMO, 2021a) details the issues raised by the MASS regulatory scoping exercise in relation to SOLAS radiocommunications provisions. The potential gaps identified include the need for new terms and definitions and requirements for automated processes. The methods proposed to address the gaps identified include the development of a new instrument with the necessity for new requirements and frequencies.

Considering the timescale of over ten years to complete the work on updates to the existing GMDSS provisions, the time to develop entirely new provisions may take even longer. In addition, as previously discussed, radio spectrum frequency is a finite limited resource which is constantly in demand from other industries and sectors, therefore it may not be feasible to expect sufficient allocation of “new frequency” for MASS operations.

Table 5 IMO Regulatory Scoping Exercise SOLAS chapter IV – Radiocommunications

Degree of autonomy	The most appropriate way(s) of addressing MASS operations (I, II, III, IV)	Reason for selecting the most appropriate way(s) of addressing MASS operations	Potential gaps/themes that require addressing
Degree One	II	Potential gaps may be addressed by amending existing instrument, possibly as they are introduced.	• New terms and definitions • New requirements for automated processes and decision support system
Degree Two	II, III	Since remotely controlled operations have not been a part of this instrument, *developing a new instrument* would be the most appropriate way to address the requirements for remote control centres. In addition, necessity for new requirements and frequencies could be addressed by developing new instrument as well.	• New terms and definitions • Requirements for remote control stations' technical issues • Functional and maintenance requirements
Degree Three	III	Since remotely controlled operations have not been a part of this instrument, *developing a new instrument* would be the most appropriate way to address the requirements for remote control centres. In addition, necessity for new requirements and frequencies could be addressed by developing a new instrument as well.	• New terms and definitions • Requirements for remote control stations' technical issues • Functional and maintenance requirements • Radio watch requirements and radio personnel • Distress, safety, and urgency calls and related requirements
Degree Four	III	Since fully autonomous ships with most probably having main control centre ashore have not been foreseen in this instrument, *developing new instrument* would be the most appropriate way to address the requirements for potential main control centres. In addition, necessity for new requirements and frequencies could be addressed by developing new instrument as well.	• New terms and definitions Requirements for main control stations' technical issues • Functional and maintenance requirements • Radio watch requirements and radio personnel • Distress, safety and urgency calls and related requirements

2.12 Cyber Security Considerations

Detailed analysis of the cyber security challenges which face the implementation of autonomous vessel operations are beyond the scope of this thesis, however, as cyber security overlaps fundamentally with communications provision a summary review of the subject has been undertaken for the completeness of this work.

In June 2017, one of the world's largest shipping companies, Maersk Line was hit by the NotPetya cyberattack. This was the first known direct attack on a shipping. In the days following the attack, email systems, cargo tracking, cargo rate, booking, invoicing and customer service systems were crippled (Greenberg, 2018). Maersk had to rebuild their entire information technology infrastructure including 4000 servers and 45,000 computers. The company's fleet was instructed to destroy onboard PC's and to provide photo evidence of the destroyed machines. The company reported that the attack cost between USD $250 – $300 million. This attack was a demonstration to the entire industry of how reliant and vulnerable connected ships, office and ports are on information technology (Oruc, 2019).

In July 2020, the United States Coast Guard issued a marine safety alert bulletin giving details of a significant cyber security incident on a ship bound for New York and New Jersey. The ship experienced significant reduced functionality of its computer systems; however, it was able to maintain control of critical ships systems such as steering and propulsion. On investigation it was noted that an onboard unprotected PC was used for processes such as the updating of navigation chart systems. The use of the PC left critical navigation systems vulnerable to attack and infection. As a result, coast guard issued guidance to ships on cyber security precautions (USGC, 2019).

As existing ships become increasingly dependent on digitization, automation and integration, cyber risk management both on-board and across shore-side infrastructures is becoming paramount. Adequate cyber risk management will be a crucial feature of autonomous vessel operations and associated communication systems. In terms of ship cyber security regulatory development, classification societies are taking an active role in the terms of the development of appropriate recommendations for the shipping industry. Classification societies are generally authorized by national administrations to perform statutory vessel survey and inspection work. The function of a classification society is to verify if a ship complies with technical rules and regulations which generally encompass the international requirements set out by the IMO.

Classification societies also contribute to maritime safety and regulation through research and development. In this regard, the International Association of Classification Societies (IACS) is recognized as the principal technical advisor of IMO (IACS, 2021).

As part of their research and development, IACS has developed comprehensive recommendation on cyber resilience which includes recommendations summarized in Table 6 with the aim of enabling the delivery of cyber resilient ships whose resilience can be maintained throughout the vessels working lifespan (IACS, 2020). IACS has collaborated across industry in order to develop guidance on how to cultivate and maintain the cyber integrity of vessels. The recommendation aims to support IMO Resolution MSC.428(98) 'Maritime Cyber Risk Management in Safety Management Systems', which requires cyber risks to be addressed in safety management systems by 1 January 2021 and on IMO MSCFAL.1/Circ.3 'Guidelines on Maritime Cyber Risk Management' (IMO, 2017).

In general, cyber security threats will only increase in the near future. Due to the complexity and reliance on multiple integrated communication systems, adequate cyber prevention measures will be needed to ensure the safe and reliable operation of autonomous and remotely operated vessels and for the safety of vessels operating in the same areas.

Table 6 IACS Cyber Security Recommendations

Title
• Recommended procedures for software maintenance of shipboard equipment and systems
• Recommendation concerning manual / local control capabilities for software dependent machinery systems
• Contingency plan for on-board computer based systems
• Network Architecture
• Data Assurance
• Physical Security of on-board computer based systems
• Network Security of on-board computer based systems
• Vessel System Design
• Inventory List of computer based systems
• Integration
• Remote Update / Access
• Communication and Interfaces

2.13 Literature Review Discussion

This comprehensive literature review has examined the existing mandatory ship communications systems and the possible requirements for autonomous vessels to interact with these existing communications requirements.

A detailed study has been carried out on international maritime communication regulatory requirements and the associated organizations and frameworks. This research included a comprehensive review of the overarching regulatory texts that apply to existing vessels and to maritime communications in general. In addition, current regulatory developments and associated timelines have been analyzed.

In reflecting upon the findings throughout this literature review the following is considered, irrespective of the level of autonomy, potential autonomous/remotely operating vessels will all require a high level of monitoring and surveillance (DNV, 2018). This is necessary for the safety of navigation the autonomous vessel, and for the safety of all other vessels and the general marine environment. The associated extensive array of monitoring systems and sensors necessary to achieve the implementation of such operations entails a corresponding increased data capacity requirement (Rødseth et al., 2013; Höyhtyä et al., 2017).

At present, safety related maritime communication systems do not provide the necessary facilities or capacity to support autonomous/remote vessel operation (IMO, 2021a; IALA, 2017). It is imperative that appropriate international regulations and standards are developed to facilitate harmonized development (Pelton et al., 2012). In terms of global communications and maritime regulatory development, the main international organizations that provide the forums for such work to take place are the ITU and the IMO (ITU, 2019; IMO, 2021c).

Due to the inclusive international nature of these organizations, regulatory developments must follow appropriate processes and established timeframes. Therefore, the development and implementation of regulatory provisions may lag behind available autonomous/remote vessel technology. Such regulatory delays have been demonstrated by the timescale which have been required to carry the modernization of the GMDSS within the IMO and ITU regulator frameworks (IMO, 2021b).

A close relationship exists between the ITU Radio Regulations and the various communications provisions of the IMO SOLAS Conventions. Updates to accommodate autonomous vessel communications requirements should be addressed within the regulatory frameworks of these international organizations. From a radiocommunications perspective, this is necessary to ensure interference free operation of all radio services. International cooperation at meetings such as the ITU WRC, is the appropriate forum to review and revise the Radio Regulations to satisfy spectrum requirements for new radio technologies while protecting incumbent radio services. Parallel regulatory work must be undertaken within the various committees of the IMO, to consider all other aspects of the operation, safety and environmental aspects of autonomous vessel operations.

In order for the required regulatory work to take place, the Member States of the international organizations must actively contribute and participate at the relevant forums to drive the agenda for autonomous/remote vessel operations. This may be achieved through member state collaboration and by the submission of mature proposals based on detailed technical research and test demonstrations, which can gain consensus amongst all member states so that necessary provisions may be supported an implemented.

Based on the above literature review, a survey has been developed to ascertain the views of maritime industry and maritime communications experts in relation to the implementation of autonomous/remote vessels. As with the literature review, this survey was undertaken to obtain a greater understanding of how autonomous vessels will potentially interact with existing mandatory ship communications systems and what the mandatory communications requirements may be for such vessels. In addition, the survey aims to obtain expert input on what may be acceptable in terms operations during limited communications availability. The survey also aims to obtain the views of experts, in terms of their perceived challenges and time scales for the implementation of regulations to facilitate autonomous and remote operations.

3 Methodology Approach

Autonomous vessel technology is essentially still in the early stages of development and currently only deployed within limited areas of operation, therefore opportunities to obtain suitable large-scale data for quantitative analysis is limited and is technically impracticable. Obtaining technical data through primary testing of autonomous/remote vessel communications is also considered beyond the scope of this research.

In addition, specific legislation relating to autonomous vessel operation and communication does not yet exist at an international level. These realities were the determining factors in dictating the adoption of an exploratory qualitative approach to my primary research. The aim of this methodology is to obtain primary data based on expert insights to further understand the technical and regulatory challenges facing future autonomous vessel communications.

3.1 Consideration of Potential Survey Methods

Based on the research literature review and secondary research, I set out to devise a methodology approach by considering the following three fundamental questions:

1. What information do I need to address my search topic?
   Based on the literature review, it is evident that fundamental communications regulatory aspects for autonomous/remote vessel operation must be addressed. Further information is required in relation to the need for autonomous/remote vessels to operate within the established procedures and requirements that apply to existing vessels.

2. Who might have the appropriate level of information?
   It is considered that appropriately experienced maritime communication, operational and legislative experts are the individuals best placed to provide the highest level of information and valid insights into the potential challenges to autonomous vessel operation.

3. What is the best method for collecting the information for analysis?
   The various advantages and disadvantages of phone/online interview calls, online surveys, and face-to-face interviews were considered, to determine which was the most suitable method to engage with industry experts.

In considering the most appropriate method to obtain useful responses from participants three survey methods were considered: phone/online interview calls, face-to-face interviews, and an online survey. Each of these potential survey methods offer various research challenges and opportunities (Sue, 2016). To determine the most suitable survey method, Table 7 was compiled to consider advantages and disadvantages for each method.

Table 7 Review of Potential Survey Methods

Survey Method	Advantages	Disadvantages
Phone/Online Interview Calls	- Immediate responses - Potentially increased engagement with colleagues - Potential for complex and open-ended questions - Interviewer can probe for clearer answers and skip irrelevant questions.	- Calls must be scheduled - Responses not anonymous which may reduce open responses - Susceptible to interviewer bias - Potential misinterpretation of verbal responses - Responses must be transcribed and interpreted
Face-to-Face Interviews	- Immediate responses - Potentially increased engagement with colleagues - Potential for complex and open-ended questions - Longer more in-depth interviews	- Limited to local interviews and subject to travel limitations - Time-consuming and expensive - Susceptible to interviewer bias
Online Survey	- Fast and Efficient - Standardized effective and consistent capture of responses - Eliminates the need for responses transcribed and interpreted - Removes the potential for misinterpretation of responses - Response data can be used - Responses anonymous which may increase open responses - Eliminates interviewer bias	- Online survey fatigue, too many digital surveys may reduce participation - Potential reduction in the complexity of questions - No potential for follow-up questions

Based on the consideration of the merits and issues of each potential survey method, the online survey option was selected. The selection of this method was further considered appropriate as it offered maximum flexibility for participants, particularly considering the various constraints imposed by the Covid-19 pandemic at the time this research was carried out. An online survey questionnaire was devised with the aim of obtaining views and insights from relevant experts on the communications challenges facing autonomous vessel operations, particularly in relation to interaction with existing mandatory communication requirements and the timescale for regulatory future regulatory implementation.

The survey was targeted at a range of experienced maritime operations and communications experts from across the industry, with participants drawn from multiple nationalities. As many of the participants represent their national administrations, all responses were anonymized to facilitate uncensored responses. By applying this approach, insights form a representative sample of relevant industry experts with an extremely high level of experience was obtained. The recorded responses and input from experts have provided a valid set of qualitative based data which can be reviewed and contribute to further analysis. In addition to the qualitative analysis of the information obtained, it was also possible to review some the options-based answers in a quantifiable way, while recognizing that such a limited sample of respondents is not suitable for quantitative analysis or statistical analysis.

3.2 Survey Participants and Duration

64 maritime industry experts were invited to participate in the survey, a total of 58 complete responses received. The expert survey was undertaken between 1st April 2021 and 1st May 2021. Participation comprised of various national radiocommunication regulatory and industry expert representatives. The participants were selected from base of national and international industry contacts which has been established over 18 years working in the maritime communications field, including attendance at IMO, ITU and European regulatory meetings. All participants were based in Europe and had a high level of international maritime communications regulatory development expertise or maritime operational experience, for example, ships' Captains, Chief Engineers and third level educators. The survey included participants from international organizations, such as the IMO, with specific and unique expertise in the field of high level international maritime radiocommunications regulatory development. The fact that participants represented two broad cohorts, that is, maritime operational and maritime radiocommunications regulatory enhanced the validity of responses received.

3.3 Methodology Description and Implementation

The Microsoft Forms software tool was utilized to produce the online survey. The choice of a ubiquitous Microsoft software interface was considered advantageous, as it provided familiarity for participants. In total, sixty-four maritime industry experts were invited to participate in the survey. Half of the invited sample group comprised of operational experts from across the maritime industry e.g., ship captains', marine engineers etc. The other half of invited participants had specific maritime communications and regulatory expertise. To maximize the number of responses and overall engagement, each participant was sent a personalized invitation email which highlighted the relevance of the survey to them. The survey invitation also highlighted the anonymous nature of all responses received. This approach was considered a success, as a total of fifty-eight survey responses were received.

Table 8 provides a summary of the questions posed within the survey and the rational/reason for asking each question.

Table 8 Summary and Rational for Each Expert Survey Question

Survey Duration: 1 April 2021 - 1 May 2021	
Survey Question	**Rational/Reason for the Question**
1. Provide a brief description of your field of work, job title or role and years of relevant experience.	To anonymously ascertain the background and to establish the level of expertise of participants.
2. Has the subject of remotely controlled shipping communications been considered or discussed within your organization?	To ascertain if participants have been linked to formal discussions on remotely controlled shipping communications. In addition, to understand if the subject is under broader discussion across the maritime industry.
3. What level of consideration has been undertaken? - Informal discussions only - Formal consideration relating to regulatory amendments - Regulatory amendments have taken place to accommodate remote vessel operations - Operation or testing of remotely operated vessels has taken place	This question was only posed to participants who indicated that discussions on remotely controlled shipping communications have taken place within their organization. The aim of this question was to ascertain the level of discussion, implementation and legal steps that have been undertaken within organizations.

4. In terms of maritime communications, rate the challenges to future remote shipping operations? - Regulatory Challenges - Technical Challenges - Cost of Implementation - Industry Acceptance	To ascertain the major challenges perceived by industry experts to remote shipping operations.
5. Do you consider it necessary for remotely controlled vessels to interact with existing maritime communication systems and procedures?	To understand if industry experts see the requirement for remote shipping operations to interact with existing maritime communication systems and procedures.
6. What extent should remotely controlled vessels comply with and be capable of interacting with existing maritime communication system requirements and procedures?	To understand to what extent industry experts see the requirement for remote shipping operations to interact with existing maritime communication systems and procedures.
7. Remote control/monitoring of the navigation, engineering, vessel safety and cargo functions present a significant additional communication data burden. Current proposals to meet remote vessel high bandwidth communication requirements are based on open commercial networks. e.g. VSAT, mobile phone networks etc. Is it acceptable for vessel critical systems to rely on such open networks?	To ascertain the level of acceptability/openness from industry experts towards a potential reliance on commercial systems which are not currently accepted for safety communications.
8. In locations with limited communication coverage, is it acceptable for critical ship monitoring systems to operate at reduced capability, where there is lower vessel traffic density and navigational hazards?	To ascertain if industry experts will accept a reduction in remote vessel monitoring in remote locations. This approach may provide greater flexibility in terms utilizing existing communication systems.
9. Where communication capabilities are reduced, what the acceptable reductions in monitoring of critical ship systems?	To further ascertain from participants the tolerable level for any reduction in remote vessel monitoring in areas with limited communications facilities.

10. Do you have experience with maritime or communications regulatory development?	To establish if individual participants have an involvement in maritime communications regulation formation, as these individuals may play a direct role in the evolution of maritime communication regulation; therefore their views may be particularly pertinent to this research.
11. In terms of regulatory development, which organizations do you have experience with?	To ascertain the specific level of regulatory development experience of participants.
12. Based on your experience of contributing to the development of regulations, what are the key processes within the various organisations that must be completed for the implementation of globally harmonised MASS communications to be achieved?	To obtain an input from all participants of their perceived necessary path for autonomous regulatory development.
13. What do you consider to be a realistic timeline for the implementation of necessary international maritime/communications regulations to facilitate the operation of remote shipping?	To obtain the views of participants on their estimated timescale for the development of required maritime/communications regulations.

4 Results and Analysis

The following is a review of the responses received for each of the survey questions. This evaluation provides a detailed analysis of the collated replies from participants obtained for each question.

Question 1- Description of work and relevant experience:

All 58 participants answered this question and provided details of their field of work, job/role, and experience. Noting that many of the expert participants represent national administrations or international organizations, all participants provided their input anonymously. These allowed participants to provide their expert opinions candidly and openly. The comprehensive answers provided by participants to this introductory question established the very level of expertise and experience of each the participants. The list of responses outlining the level of experience is compiled in appendix 1.

Question 2 - Has the subject of remotely controlled shipping communications been considered or discussed within your organization?

A higher than anticipated number of respondents, that is, 46 out of 58, indicated that remotely controlled shipping communications has been discussed within their organizations. It is considered likely that this higher-than-expected number may indicate this question may have been somewhat misunderstood by respondents. It is likely that participants have discussed remotely controlled and autonomous shipping in general terms within their organizations. Significantly, 28 of the 31 participants with experience in maritime or communications regulatory development answered yes to this question. This may indicate that there is widespread consideration ongoing among regulatory experts on this subject.

Question 3 - What level of consideration has been undertaken (within organizations):

The breakdown of the 46 responses to question 3 (Figure 10) are insightful. Recognizing that a significant number of participants, that is, the highest single cohort of 26, indicated that only informal discussions in relation to remotely controlled shipping communications has taken place within their organization which was less than half of the total responses.

It is noteworthy that 22 of the participants indicated that formal consideration has been given to regulatory amendments or regulatory amendments have taken place to accommodate remote vessel operations. In terms of the implementation of autonomous vessel operations regulatory development is an essential, therefore these responses are significant, as they indicate that steps may be underway at a national level to address regulatory barriers. In addition to potential regulatory developments, 10 participants have indicated that operation or testing of remotely operated vessels has taken place within their organization; this is also a positive indicator in terms of future autonomous vessel operation.

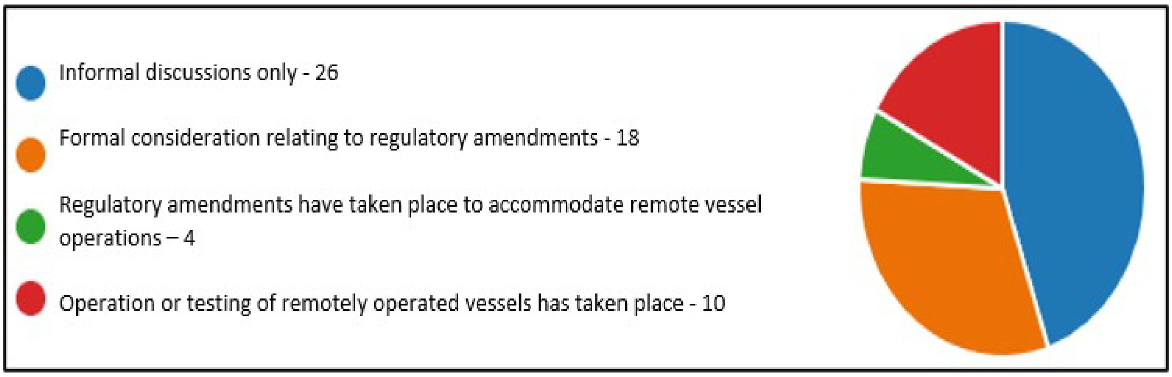


Figure 10 Responses to Question 3 Level of consideration undertaken

Question 4 - In terms of maritime communications, rate the challenges to future remote shipping operations:

Based on the responses to question 4 summarized in Table 9, it is apparent that the majority of participants view regulatory challenges and industry acceptance as the primary barriers to remote shipping operations. Of the 31 participants that indicated that they have experience with maritime or communications regulatory development, only one indicated that regulatory challenges are a minor barrier. Based on the specific experience and expertise of this cohort of participants, it is likely that their pessimistic view of the regulatory challenges is likely to be well founded.

On the contrary to the perceived regulatory and industry acceptance challenges, a high majority of respondents do not view technical challenges as a major barrier. This may indicate that there is a perception amongst expert participants, that remote shipping operations are possible with existing technologies. Based on the responses regarding the cost of implementation, this is considered as a potentially greater challenge than technical obstacles.

Table 9 Responses to Question 4 Rating of maritime communications challenges

Regulatory Challenges	
Minor Barrier	2
Standard Development Challenge	24
Major Barrier	32

Technical Challenges	
Minor Barrier	15
Standard Development Challenge	37
Major Barrier	6

Cost of Implementation	
Minor Barrier	9
Standard Development Challenge	27
Major Barrier	22

Industry Acceptance	
Minor Barrier	11
Standard Development Challenge	18
Major Barrier	29

Question 5 - Do you consider it necessary for remotely controlled vessels to interact with existing maritime communication systems and procedures:

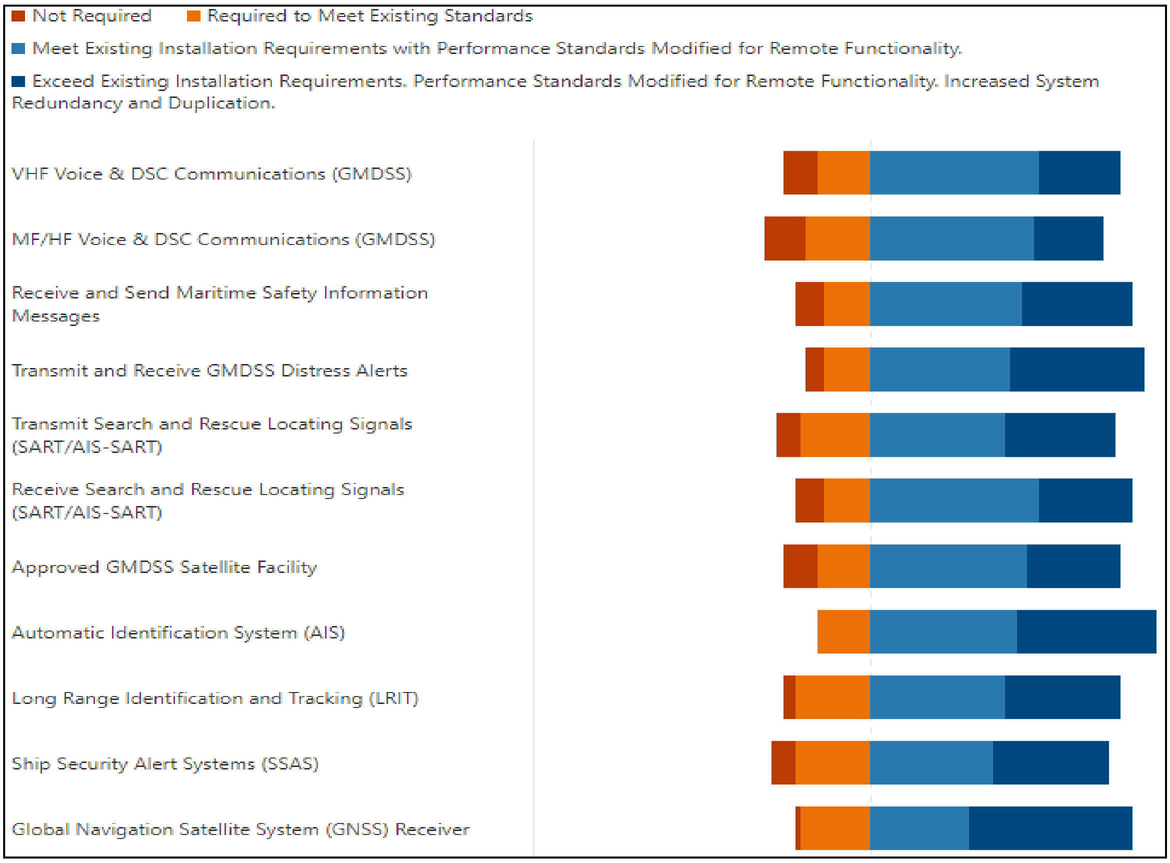
All 58 participants concurred that remotely controlled vessels should interact with existing maritime communication systems and procedures. Based on this unanimous response, it is likely that interaction with existing communications will be necessary to achieve wide industry acceptance. Such requirements will therefore have to be factored into autonomous vessel development. This may present both technical and regulatory obstacles and delay implementation of autonomous operations.

Question 6 - What extent should remotely controlled vessels comply with and interact with existing maritime communication system requirements and procedures:

Based on responses to the question 6, graphically represented in Table 10 below, a clear majority of participants see the need for remotely controlled vessels to meet or to exceed existing performance requirements for maritime communication. The need to meet or exceed existing standards was broadly consistent for all current ship mandatory communication systems. Fulfilling such performance requirements may also be considered necessary for wide industry acceptance of autonomous vessels and essential for such vessels to operate in the same areas as conventional craft.

Any requirement to exceed current onboard performance standards may be fulfilled through redundant systems with additional emergency power supplies and fallback equipment. Any new performance standards, or amendments to existing standards to facilitate remote/autonomous operation, will require detailed regulatory assessment, as each piece of existing equipment is supported by an intertwined set of regulatory instruments and technical performance standards of the IMO (IMO, 2020a) and recommendations of the ITU (ITU, 2022b).

Table 10 Summary of Responses to Question 6 Compliance and interaction with existing requirements



Question 7 – Considering the increased data requirements of remotely controlled vessels is it acceptable for vessel critical systems to rely on such open networks on open commercial networks?

Based on the responses to question 7, summarized in Table 11, there appears to be a low likelihood of the acceptance of a reliance on open commercial networks and systems. A majority of 35 participants indicated that the use of open commercial networks in conjunction with established communication systems is acceptable. A significant number, 18, also indicated that the use of and reliance on open commercial networks/systems is not acceptable.

Of the thirty-one participants who indicated that they had experience with maritime or communications regulatory development and are therefore more likely to be involved in overall rules development and implementation, only three responded that the use of and reliance on open commercial networks/systems is acceptable. Seven responded that the use of and reliance on open commercial networks/systems is not acceptable, while twenty-one of this cohort indicated that the use of open commercial networks in conjunction with established communication systems is acceptable.

The responses received to question 7 reinforce a perceived need for future autonomous or remote vessels to integrate with existing safety related communications systems. If the reliance upon commercially available networks is not acceptable to regulatory decision makers, then a major barrier in terms of available data capacity will exist as found through the literature research, existing approved satellite systems do not currently have adequate capacity to support autonomous operations.

Table 11 Summary of Responses to Question 7 Consideration of increased data requirements

Response Option:	**Number of Responses:**
The use of and reliance on open commercial networks/systems is acceptable.	**5**
The use of and reliance on open commercial networks/systems is not acceptable.	**18**
The use of open commercial networks in conjunction with established communication systems is acceptable.	**35**

Question 8 - In locations with limited communication coverage, is it acceptable for critical ship monitoring systems to operate at reduced capability, where there is lower vessel traffic density and navigational hazards?

The responses to question 8 summarized in Table 12 are definitive, with 43 out of the 58 participants indicated that it is not acceptable for critical ship monitoring systems to operate at reduced capability, where there is lower vessel traffic density and navigational hazards.

Of the thirty-one participants who indicated that they had experience with maritime or communications regulatory development, only seven indicated that partially reduced monitoring is acceptable. Based on these responses, the requirement for a consistent high level of monitoring will dramatically increase data/communication requirements. If regulatory decision makers adopt the views expressed in the replies received to question 8, there may be significant limitations imposed on the areas in which autonomous vessels may operate due to insufficient data coverage.

Table 12 Summary of Responses to Question 8 Acceptability of reduced communications capability

Response Option:	**Number of Responses:**
Yes, it is acceptable for critical ship monitoring systems to operate at reduced capability, where there is lower vessel traffic density and navigational hazards.	**1**
No, it is not acceptable for critical ship monitoring systems to operate at reduced capability, where there is lower vessel traffic density and navigational hazards.	**43**
Partially reduced monitoring is acceptable for critical ship monitoring systems to operate at reduced capability, where there is lower vessel traffic density and navigational hazards.	**14**

Question 9 - Where communication capabilities are reduced, describe examples of acceptable reductions in monitoring of critical ship systems.

Fifteen insightful responses were received for question 9. These responses proposed several options including a reduction video monitoring in areas of reduce communication capacity. It was noted that definitions are required in the area of autonomous shipping. For example, consideration could be given to different operational area protocols, such as piloting in harbors/ports and approaches; coastal passage; deep sea transiting. One specific response which noted the complexity of this issue underlined the need for such vessels to be dealt with on a project-by-project basis and that the process for risk mitigation as described by IMO Circ.1455 “Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments”, should be followed.

Several respondents proposed less frequent uploading of information based on a reduction in video monitoring. This would significantly reduce data transfer bit-rate requirements in areas of lower traffic density. In such areas, fewer navigational hazards should reduce the probability of collision. The frequency of ship course changes should therefore be lower. Reduced engineering and cargo monitoring and a reduction in radar data may also be acceptable in low traffic areas. Situational awareness, both navigational and ship´s internal safety (fire detection) should be prioritized as these are the areas where human interactions are most likely to be needed. Sense and avoid system and other possible AI solutions should be considered to support safe navigation of a vessel when operating in locations with limited communication possibilities.

Alternative options proposed that MASS 2 ships can disconnect all communications to remote operation center if there are crew onboard. Surveillance systems based on the radar information and camera visual confirmation regarding targets observed with alarm signal to alert operators on when required. This will depend upon IMO MASS Degree 2 or Degree 3 definitions. If a vessel is partially manned, then some operations can still be carried out by crew. Limiting the areas where such vessel may operate may be beneficial. Areas of operation would be identified on a vessel-by-vessel basis. If vessel system and operational reliability are sufficiently high, and all external forces (wind / sea conditions) are stable, a "sleep" mode of communications could be adopted. Nonetheless in these circumstances, backup storage device recording may need to be communicated in the event of an alarm or dangerous vessel condition state to provide remote operators with full situational awareness.

Question 10/11 - Do you have experience with maritime or communications regulatory development? In terms of regulatory development, which organizations do you have experience with?

Significantly, 31 of the 58 participants indicated that they have experience with the niche area of maritime or communications regulatory development. The majority of these participants indicated that they have regulatory development experience within IMO and ITU. As the IMO and ITU are the two relevant United Nations Specialized Organizations involved in global maritime and communications regulatory developments, the experience of this expert cohort provides a unique insight into the real challenges facing the communications and regulatory aspects of the implementation of remotely operated vessels from individuals who contribute within these organizations. In addition, participants also indicated regulatory development experience within relevant national and European Union bodies. The perspective of these communication regulatory experts is also balanced and complemented by the input and responses from the other general maritime industry participants.

Question 12 - Based on your experience of contributing to the development of regulations, what are the key processes within the various organizations that must be completed for the implementation of globally harmonized MASS communications to be achieved?

The input provided by participants based on their experience of contributing to the development of regulations which is contained in Appendix 1 is very insightful. It is significant that each participant outlined a variation of the key processes required within the various organizations that must be completed for the implementation of globally harmonized MASS communications to be achieved. The need to follow the regulatory development processes within the ITU and IMO was a primary theme within the responses. In addition, the need for ITU technical studies and the amendment to other international regulations was also highlighted. A key component is the need for communication technology to be proven and for stakeholder engagement, risk and impact assessments will also be required. In addition, the overall demand for autonomous vessels by the maritime industry needs to be assessed.

The challenges and delays facing the aeronautical industry on the implementation of unmanned aerial vehicles is highlighted in one detailed response. The aviation industry has so far been unable to solve the associated regulatory issues after ten years of regulatory work on the matter. This work also noted that the use of commercial communication systems should not be taken into consideration by the regulation for safety related applications. Such challenges are likely to pose similar issues within for unmanned vessels at sea. It was also noted that if remote vessels experience interference to communication links, it may be very difficult to determine the source and even harder to enforce regulatory requirements. This is complicated due to the potential for multi- jurisdiction involvement. These factors may take delay the resolution of any communications interference and may impact of vessel operation if such interference affects the safety of operationally critical communications link.

The various issues and approaches highlighted in the responses to question 12 underline the complexity in resolving the associated regulatory factors for the implementation of remote/autonomous vessels. These inputs also emphasize the difficulties of achieving international consensus on these complex regulatory matters.

Question 13 - What do you consider to be a realistic timeline for the implementation of necessary international maritime/communications regulations to facilitate the operation of remote shipping?

Based on the responses to question 13 summarized in Figure 11, it is apparent that participants with relevant regulatory experience view a long-term timeline for the implementation international maritime/communications regulations to facilitate the operation of remote shipping.

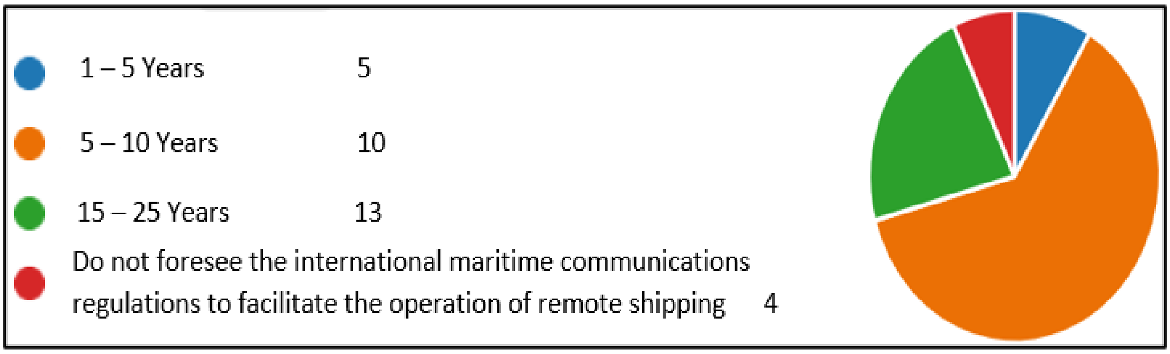


Figure 11 Responses to Questions 13 Consideration of a realistic timeline

5 Results Discussion and Review

Based on the high number of responses and the level of maritime industry experience of each participant who took part in this survey, the information and insights obtained are considered as making a valuable research contribution to the developing field of autonomous vessel operations. Each participant provided a summary of their relevant maritime experience, the details of which, is contained in Appendix 1. This survey has successfully obtained the views of these experts on how they view the need for autonomous vessels to interact with existing mandatory ship communications systems and which existing systems should be considered as mandatory for autonomous vessels. In addition, the survey obtained expert input on the level acceptability of autonomous/remote vessels operations in area of limited communications availability. The survey also obtained the unique views from experienced experts in the field of international maritime communications regulatory development, in terms of their perceived challenges and the potential time scales for the implementation of necessary regulations to facilitate autonomous and remote operations.

The broader responses received from experts highlight the challenges facing the standardized implementation of autonomous vessel. It is apparent that there is a deficit between existing communications facilities and what may be considered as acceptable in terms of vessel operational safety. Notably, 28 of the 31 participants with experience in maritime or communications regulatory development indicated that the subject of remotely controlled shipping communications has been considered or discussed within their organization. This indicates that the topic is relevant within the regulatory sector.

In addition, participants from the cohort with regulatory experience provided input on the various processes required within the international organizations that must be completed for the implementation of harmonized communications for autonomous. This emphasized the need to follow the complex and gradual regulatory development processes within the ITU and IMO which are based on the principal of regulatory development through consensus.

All 58 participants concurred that remotely controlled vessels should interact with existing maritime communication systems and procedures. A large majority see the need for these vessels to meet or to exceed existing performance requirements in terms mandatory maritime communication requirements.

In relation to operations in areas of reduce communications coverage, a significant majority of 43 participants indicated that it is not acceptable for critical ship monitoring systems to operate at reduced capability, in areas of lower vessel traffic density and navigational hazards. Due to current communications coverage constraints, this may prove to be a geographical operational limiting factor for future vessels.

In consideration of the increased data requirements of remotely operated vessels, a majority of 35 participants indicated that the use of open commercial networks in conjunction with established communication systems is acceptable. However, a significant number, 18, also indicated that the use of and reliance on open commercial networks/systems is not acceptable. Of the 31 participants with regulatory development experience, only 3 responded that the use and reliance on open commercial networks/systems is acceptable. Seven responded that the use of and reliance on open commercial networks/systems is not acceptable, while 21 indicated that the use of open commercial networks in conjunction with established communication systems is acceptable.

The majority of participants view regulatory challenges and industry acceptance as primary barriers to remote shipping operations. Based on the experience and expertise of participants, this view of the regulatory challenges is likely to be a realistic assessment. The majority of respondents do not view technical challenges as a major barrier, indicating that there is a perception amongst participants that remote shipping operations are possible with existing technologies. Respondents indicated that the cost of implementation is a greater challenge than technical obstacles.

In relation to question 13 regarding a realistic timeline for the implementation of necessary international maritime/communications regulations to facilitate the operation of remote shipping, which was only posed to participants with relevant regulatory experience. There appears to be a consensus view that a long-term timeline is likely. This emphasized with 23 out of 31 responses indicating a timescale of over 5 years.

6 Discussion on Key Research Questions

Following the comprehensive literature review and survey study carried out, the key research questions set out have been addressed as follows:

What are the existing mandatory ship communications systems, and will autonomous vessels interact with these?
The existing mandatory ship communications systems have been thoroughly identified and studied. Based on the literature analysis and survey input from experts, it is highly likely that autonomous vessels will be required to interact with these existing systems. As such, future autonomous vessels will likely to be required to install many of these existing mandatory systems.

Can the potential communications requirements for autonomous vessels be accommodated within the existing maritime communications systems and regulations?
It is not currently possible for the communications requirements of autonomous vessels be accommodated within the existing maritime communications systems and regulations. This will necessitate significant maritime communication regulatory developments. It will also require significant technological development, particularly in the area of maritime satellite capabilities and coverage.

Considering previous international rules development, what is the potential timeline for necessary regulatory changes to accommodate autonomous/remote vessels?
Due to the complex international nature of maritime and communications regulatory development, which is based on consensus, and which may involve competing agendas, it is likely that the timeframe for necessary regulatory changes to accommodate autonomous/remote vessels will be over ten years.

What are the views of maritime industry and maritime communications experts in relation to the implementation of autonomous/remote vessels?
Maritime industry and maritime communications experts do not underestimate the complex nature of the regulations which must be put in place to facilitate implementation of autonomous/remote vessels. They see regulatory developments as a greater challenge than that of technological barriers. They also see, based on their experiences in the relevant forums, that regulatory developments may take some time.

7 Conclusion

It is evident that all autonomous and remotely operating vessels will require a high level of monitoring and surveillance. In addition, it is recognized that there is a need for such vessels to interact with and comply with existing vessel communication obligations. These essential requirements will necessitate extensive additional communications structures and systems which are not presently in place from a regulatory perspective. To appropriately address the communications technical and regulatory deficit, it is crucial that international regulations and standards are developed to facilitate communications harmonization and vessel interoperability. The input and analysis of the research survey carried out contributes a unique insight from experts in the wider maritime field and from the field of maritime communications regulatory development. The insights obtained are significant, as they are based on extensive relevant independent experiences. These inputs emphasize the need for maritime communications regulation to facilitate autonomous/remote operations.

In terms of the necessary communications and maritime regulatory development, it has been identified through this research and from the expert responses received that the ITU and the IMO are the primary international organizations with the relevant forums for such work to take place. However, regulatory development and implementation is complex and involves the consideration of varying national and regional perspectives which may not always align. Therefore, the regulatory process is likely to take time and these necessary structures will lag behind autonomous/remote vessel technology. Additionally, communications equipment manufacturers may also be reluctant to commit significant development resources to the area of autonomous shipping until there is a clear set of performance standards and regulatory criteria in place.

In order to advance the regulatory process, the onus is on national administrations who have a direct interest in the field of autonomous shipping. These administrations must collaborate and actively participate in the regulatory processes within appropriate regional and wider international forums to drive the necessary changes. Regulatory proposals should be carefully detailed and should be supported by comprehensive studies. In the absence of acceptable regulatory proposals from administrations to facilitate autonomous vessel operations, the current regulations which do not accommodate these vessels will remain in place. If there is a suitably robust economic and environmental argument for the introduction of autonomous vessels, industry and political influences will drive and accelerate the necessary regulatory developments.

8 Critical Review

This thesis research has successfully investigated the high-level communications technical and regulatory challenges facing the future implementation of autonomous vessel operations. However, as the associated technologies and regulatory discussions are only in development stages, the conclusions on potential solutions to the questions raised within this work are not definitive.

The comprehensive literature review carried out provided a solid basis for developing an informed and relevant survey which received a high level of engagement from a broad range of international regulatory decision makers and operational experts in the maritime field. The knowledge gained from the thorough literature research which was undertaken enabled this survey to be well informed and for it to pose pertinent questions on the subject to an audience of international experts.

The information obtained through the survey carried out provides an informative insight into the perceptions of relevant international experts as to what the main communications technical and regulatory challenges are in terms of autonomous vessels. In providing an insight from experts of what the primary challenges are facing autonomous vessel communications, the results of this research raise several further questions. It is possible that further information and detail could have been obtained from experts if this survey could have been supplemented with follow up face to face interviews. Such an approach would have provided the opportunity for additional input from participants and would have facilitated more open-ended questioning. Unfortunately, time limitations and Covid-19 restrictions meant that interviews could not take place in a physical setting. The issues and challenges highlighted within this investigation require further study which is beyond the scope of this research.

In order to better understand and develop the results of this research, further detailed examination of the mechanisms to advance regulatory change is required. In addition, research and case studies of national legislation could further enhance the understanding of this complex topic. The research within this thesis is concentrated on the broader international regulatory environment, however, further assessment beyond this scope with specific focus on countries which have appropriate regulations in place could enhance the understanding of this topic further.

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10 List of Figures

11 List of Tables

Appendices

Appendix 1 Description of Survey Participants Work and Experience

Radio communications engineering (Radio Surveyor). National representative at IMO, ITU, CEPT, ETSI for maritime radiocommunications matters. Previously worked for national search and rescue agency, worked for the ITU 7 years, worked for IMO 2 years.
Lecturer in Marine Electrotechnology (ETO Cadet training) at the National Maritime College for 16 years. Previously an Electro Technical Officer on oil tankers and cruise ships.
Ship Surveyor & Naval Architect. 20+ years. Flag surveyor, IMO delegate at MSC and head of delegation at SDC, national representative at EU commission passenger ship safety expert group, Port State Control Officer.
Marine Electronics Service/ Survey 20 years
Master Mariner and former ships Master with experience on Bulk Carriers, container Ships, LPG Carriers, Offshore Supply vessels, research vessels, Ro/Ro passenger ferries, High Speed passenger craft, Cruise Ship, sail training vessel. Hold an MSc (Shipping Operations) Associate Fellow of the Royal Institute of Navigation Currently Nautical Surveyor with Irish Maritime Administration. Ireland representative to the IMO NCSR Sub-committee, International Hydrographic Organization, North Sea Hydrographic Commission, Ad Hoc expert sub-group under the HLSG on Autonomous Shipping and VTS (MASS). Board member of INFOMAR (Ireland's seabed mapping programme). Time at sea 19 years, time ashore 12 years
SAR Systems Development Officer with the Irish Coast Guard, developing RCC integrated coordination management systems and Maritime Search and Rescue communications protocols
Maritime information and communications technology R&D, consultancy, and training.
Nautical Surveyor & Port State Control Officer with Maritime Administration. 22 years at sea on merchant ships including 10 years as Master of large Ro Pax ships.

Nautical Science including communications, previously in command, now educator, 20 years at sea, 25 years in education.
Head of Kalmar Maritime Academy, 20+ experience within Maritime business
Deck Officer and Shipping Operator for Owners and Charterers, 17 years of experience.
Aids to Navigation provision including eNavigation services. Director. 23 years as a naval officer including two periods in command. 8 years in naval comms & IT. 3 years in management of maritime SAR. BSc in IT and MSc in Technology Mgt.
Master Mariner. Currently Ch. Officer on CSV offshore vessels. Approx 15 as an Officer.
3 years at maritime radio/radar college - UK 1973 -1976. 9 years as deep sea cargo vessel Radio Officer 1976 - 1985. University UK - Electronic Communication. 1987 to date – Large Global Maritime Radio/Electronics Company, currently as Compliance Manager London Technical Manager, then European Technical & Service Director based in Amsterdam. Now with responsibility Radio and Navigation MED item 5.XX and 4.XX equipment (The company have about 45 current MED Certificates). RED non-SOLAS equipment certification and attending ETSI meetings for ETSI TGMARINE for development of marine technical EN & ETSI performance standards.
Technical adviser for maritime safety, radiocommunications, VTS, Marine spatial planning and e-navigation. 10 years in merchant shipping, 25 years in maritime administration including 10 years in SAR as RCC manager and SMC.
Marine & Offshore engineering, 21 years of experience Rules Development for MASS, 4 years of experience
Maritime radiocommunications. More than 25 years of experience.
I have been in charge for maritime issues within our Radiocommunications Agency for appr. 30 years and involved in maritime radio within CEPT, ITU-R WP 5B and IMO (1st COMSAR, later NCSR). Furthermore, I have been chairing the CEPT Maritime Project Team for more than 10 years.

Head of Radio Location Radio Communication at the National Maritime and Hydrographic Administration. I am in the position for about 21 years. In this position I am the lead in the radar test laboratory to test marine radar system according industry standards and working on standardisation at ITU-R working party 5B for maritime communications and Radar issues as well as within IEC TC80 and national Standardisation Bodies supporting the work of ISO TC8 SC 6 as well as WG 10.
25 Years Telecom Engineering Experience across many areas including Technical Engineering, Government Policy, Legislation and Regulation.
Liner shipping (transportation of passengers and cargo, RoPax), 2nd Officer, 7 years
Doctorate in communications. Senior role within the National communications regulator.
Previous work: Professional Seafarer for over 30 years. Current Work: In the Regulatory section of a National Maritime Administration for over 12 years.
Master Mariner, Ships Captain. Tankers, Research Ships, Bulk Carriers, PSV's and Ferries. Experience working in maritime education and regulation and well as Port Operations. In the marine industry for 20+ years.
Station Officer, Marine Search and Rescue, 15 Years
Engineering and Ship Surveyor, National Maritime Transport Regulator. 12 years in the role. I am a member of the Irish Delegation to the EU, ILO and IMO. I deal primarily with Safety, Maritime pollution prevention and maritime economic protection.
1st engineer of Cruiseferry. From 3rd engineer to Chief engineer totally 11 years.
The management of a maritime SAR and casualty response service. Including elements of domain awareness and navigational safety. Based with the IAMSAR and OPRC convention framework.
Naval Architect, Flag State Surveyor with 19 years' experience.
Maritime and aeronautical search and rescue, maritime and aeronautical radio communication, radio frequency management

Engineer working as civil servant in the National Network Agency. Responsible for all basic issues dealing with maritime radio communication and radio communication on inland waterways. I participate in several international working groups as ITU R WP5B, IMO NCSR, CEPT CPG, ECC FM 58 and Committee RAINWAT. My work includes frequency management, ship station licence, numbering, and other administrative issues.
Flag state ship surveyor for 17 years.
Radio Officer and ElectroTechnical Office Electronic officer 33 years. Ist ETO / Snr Comms officer 7 years P&O Cruise Lines. Watch Officer Irish Coast Guard at MRCC Dublin 2 years Marine Radio Surveyor 7 years to present
I have over 20 years' experience in dealing with and development of Maritime Satellite Communications systems.
Technical Officer in maritime electronics for bridge navigation and communication
Nautical Policy Advisor working on the modernization of GMDSS and MASS related issues for maritime administration since 3 years, previously navigation officer for 10 years
8 years as a chief electrical engineer onboard Ro-Ro and Ro-Pax vessels.
Policy making national government; for over 15 years attending IMO and other relevant international meetings.
Naval Architect responsible for regulations for MASS at a flag state. Has been working as a regulator for 25 years.
I provide advice on radio spectrum and its management. I have been involved in radio spectrum management for over 25 years. My work includes participation in international meetings.
VTS operator today, background from coastal cruise line as safety officer with DO certificate class 2. 4-5 years' experience at sea. Also 2,5 years' experience as product advisor and instructor at Kongsberg Maritime working on navigational equipment.

I am currently the Maritime Safety Engineering Manager at one of only two Approved GMDSS Satellite Providers, with 6 years of experience in the Satellite Communications industry.
Maritime Radio/radar technician, 30 years’ experience
I am retired Navy officer with 25 years’ experience of military operations with background of ten years as a deck officer and three years as a commanding officer of a Navy vessel. After the military career I have worked eight years in the Electronics industry as the Chief Program Officer being responsible for our company´s projects and quality. The company´s main products are Combat and Mission Managements Systems for Navy and Coast Guard ships.
Chief Technical Officer in the marine electronics industry, with 14 years' shore-based experience.
Anti-collision IMO Radar provider, my job title is Product Manager with 35 years of experience.
Technical director at a major navigation & communication equipment manufacturer. 40+ years in maritime, originally in R&D
Group Operational Director (GOD) for Group of Maritime Service Stations located within 14 Countries worldwide. I have 14 Years’ experience within the maritime industry with 11 years prior to that within the military (aviation)
Product Management Director, ex Navy LtCdr, working with navigation equipment and cartography. Over 30 years’ experience.
Maritime Consultant on e-Navigation, ship reporting, Port call, MASS. 17 years
Product Manager, 15 years
CEO, 20+ Years, Engineer
I am an ex Radio Officer with 30+ years experience in maritime and now oversee Safety, Security and look after the yachting and passenger sector for one of only two Approved GMDSS Satellite providers Maritime business unit within the satellite operator.

Management for MASS technology and development, Manager, Experience for this development is 4 years
I have been supplying, fitting and servicing communications, navigation and fishfinding marine electronics to the Irish commercial fishing industry since 1986, as self employed / company owner. Overall 37 years experience.
Managing Director of a marine electronics company from India. I have 30 years experience in ship tracking and communications. A lot of Regulatory experience: 7 Technical committees in Etsi, CEPT, ITU, CIRM, IMO on the revision of GMDSS. Have run a satellite e-mail hub and designed ship communications systems.
Civil, Electronic and Marine engineering with Ship surveying, technical teaching and Health and Safety with administrative management

Appendix 2 Responses to Question 12 - Expert Views on the Implementation

Communications

1 Introduction 2 Formation of concept 3 Extensive operational and technical studies formulated into reports 4 Period of live testing and trial operation also formulated into reports 5 Acceptance of concept 6 Period of regulatory review and revision, involving development of resolutions and recommendation as international standards and the amendment of treaty text for international conventions and agreements. Timescale 20 years.
The main issues will be to adopt changes to various conventions to allow for this kind of vessel among then SOLAS, STCW, UNCLOS, Colregs. It may be necessary to introduce a standalone code for MASS vessels, in particular the design element. Legal clarity will be required as to where responsibility will be in the event of an accident or legal actions.
Proven technology development for MASS operations; stakeholder engagement; standards to be developed internationally and agreed nationally. Risk analysis to be provided on navigation and communications.
IMO members in conjunction with Class Societies (probably via IACS) will be the main movers and shakers to continue getting the MASS project moving forward. Until IMO work has been agreed the other players along the chain are unable to move forward at a great rate.
Communications for remote control/monitoring of MASS should be separated from GMDSS radiocommunications. GMDSS frequencies should not be perturbated by communications for remote control/monitoring. Frequencies for communications for remote/control to be identified at ITU on a clear request of IMO.
- Alignment on terminology - Coordination between IMO committees (MSC, LEG, FAL)
Basically, the operational requirements need to be established in IMO fora, particularly in terms of safety. However, in terms of radio licences and certificates it needs to be addressed to IMO/ITU experts. In terms of potential needs for frequency spectrum in additions to the current spectrum allocated for maritime radiocommunications, this needs to be discussed in ITU.

1st debate in IMO on all ins and outs of the issue incl. an impact assessment. How eager is the membership of IMO to implement MASS? (See also the outcome of the NCSR scoping exercise) 2nd: address within ITU-R as well as at EU level. Also put the issue on the agenda of a future WRC.
The major issue will be the definition of safety and security necessary related to access to frequencies and how this can be ensured at all times in all operation conditions. As most of MASS may operate outside shore contact satellite communication will be vital. As satellite resources are limited the usage of commercial operators will be required but by additional methods the access to fall back scenarios have to be implemented to ensure safety of navigation. In this context it should be noted that the frequencies allocated to the maritime mobile satellite service is quite limited and under hard pressure of the IMT industry, certain parts of the bands may not be accessible close to shore and the C-Band feeder links may also be interfered by IMT at the ground station sides of the existing services. It has to be noted that the aeronautical industry is working on the command and Control links to UAVs since a long time. The industry is facing the challenge that links for the fixed satellite service are available but the usage for the mobile service are not taken into consideration by the rules especially the usage for safety applications was never the intention. It has further be noted that at the time the means implemented to ensure that interferences are removed from a certain frequency/band are working between hours and days - in my view it cannot be accepted that when a MASS or several of these are subject to interference in a certain sea area that it may take hours or days to remove this threat - also in this area new methods are to be implemented - but how to enforce this over the border of your own jurisdiction? Noting further that the measurement service to identify interference is operating on national level it is not known to me that beside naval resources civil authorities are carrying measurements on the open sea to find infringements and to remove them. In this context it has to be noted and taken into account that commercial contracts requesting an accepted downtime - and those who want to implement commercial products for safety application have to answer the question how long can a down-time be accepted? Is the service such V-Sat can be applied as a comand and control link also be regulatory means? In Regard to question 12. as noted above at the time studies are carried out on experimental bases, has anyone looked into regulatory implications? Can the communication service used be taken for this, will it be reliable enough und all conditions? is the task carried out safety related? what will happen if the link is interfered or break down is a backup or fall back available - how long can it be accepted that I lose the link? As noted above the aeronautical community is looking into this topic for appr. 10 years and that industry was not able to solve the regulatory issues with a high amount of energy and personal until now - at the time I do not see that the maritime community will be able to provide sufficient resources to solve the regulatory questions open.
International Standardisation and Regulation policies have to be in place in order for MASS to function and if necessary new international agreements have to be put in place which is not straightforward and takes time and effort.

1. An industry agreed global standard for MASS 2. Very clear what type of spectrum (VHF, UHF, MMwave) and how much spectrum is required. 3. Very clear on delivery platform(s) - land based, satellite 4. Get a CEPT decision in place (if possible) so Europe starts implementing - use threat of losing out to other regions as a driver 4. A strong lobby at the ITU from the IMO via Member States. 5. Get the issue to be a priority in the EU spectrum policy program which will lead to EU forcing MS to push this issue at ITU.
International consensus must be achieved at the UN maritime bodies first. That can take a substantial amount of time to achieve both a regulatory framework (to take account of existing legislation while drafting a new mandatory regulation that is adopted and ratified via transposition into national legislation by member States) and technical standards (the development and or modification of control and management systems).
Initial robust scrutiny via technical sub committees, sponsorship within assigned cooperation groups and development of a consortium of sponsoring Member States, contracting parties or others.
IMO, ITU regulation
Public consultation, consideration of legal conflicts, consideration of technical conflicts.
I think similar to some of the developments in GMDSS in recent years there is no clear path and that will be more that half of the battle. A key part of moving forward with MASS communications will be dealing with the issues between some of the organisations mentioned and forging a new path and creating a new framework for this new type of communications.
Completion of the regulatory scoping exercise at IMO, and completion of the identified regulatory work. A similar exercise to be undertaken by the ITU Radiocommunications sector.
1) development of national/regional agreements on trials (within the requirements of MSC.1/Circ.1604 and EU guidelines on MASS trials) in order to build concrete experience with what the MASS concept encompass 2) development (based on the experience build here above) of a dedicated and comprehensive IMO instrument that could make use of a tacit acceptance procedures

The ITU has defined procedures for making changes to the radio regulations. Bypassing or fast tracking such procedures cannot be guaranteed. These procedures take time but are "standard development" procedures. EU law has its own standard development processes. Whilst work within bodies such as CEPT (and perhaps ETSI) can be flexible and understanding to the communications industry and technology development, global harmonisation by its nature means getting acceptance from parties all across the world, not just in the technologically advanced or open-minded countries. The ITU can sometimes bring "political elements" into the mix. If it transpires that different technical solutions are proposed by parties from different parts of the world, the respective countries at ITU can be supportive of "their" technology solution and oppose solutions from other countries. This could delay or hamper the work. It is likely that a system would be accepted/adopted in the end, just not clear how quickly adopted.
Harmonization with GMDSS Standards will play a large role, along with Integration into IAMSAR manual which will require its own method of handling a partially or fully remote vessel in a distress situation, will require new thinking along with assessing environmental impact of such a situation.
IMO instruments must be updated/revised in line with the outcome of the Regulatory Scoping Exercise. Whilst there are other regulatory processes to be completed (e.g. ITU), IMO is in my experience the slowest moving of all maritime standards bodies. IMO will always be playing catch-up with industry.
Implement the SOLAS with additional minimum carriage requirement for MASS.
MASS communication is split into two parts: 1) regulatory communication as today with other ships and shore; 2) private communication between MASS and remote-control center. I am quite sure that IMO will set GBS (Goal Based Standards) rules for the second part. I mean that IMO do not say that one shall use, for example VSAT, but IMO will say that there shall always be at least two communication links using different method between MASS and remote control center (good example is Yara Birkeland, Norwegian authorties required communication by mobeile phone network, by satellite communication and by private radiocommunication network installed along the route of the sjip in the Oslo Fjord area). We cannot be so naive that MASS could be left alone uncontrolled. The consequence is nuclear power plant level thinking for the communication MASS and remote control center. The regulatory communication is much easier as there is no need to have anything more than today, just faciliate remote operation or operation by artificial intelligence.
Collaboration with governing and no-governing bodies with the support of external stakeholder. CIRM for example harmonized and advised prior to reaching the decision process where there is a vote. having already been agreed or discussed with the experts within their field to gain common consensus and understanding.

IMO performance standard, IEC/ISO test standards, possibly ITU frequency allocations.
IMO, ITU, IEC, IALA, IHO and related standards and guidelines need to be followed. The standards of supporting organisations (RTCM, IPCDMC...) defined in the IMO Maritime Services descriptions and of relevance for MASS need to be followed
IMO standards
About 4-8 years of convincing major flag states to implement a common global standard with real teeth and interoperable. This will also require standards for shore facilities, the interconnection to the RCC's and among RCC's and national budgets to be allocated. Insurers will need to have very clear policies on liability and coverage (especially if systems can and will be hacked). Lastly Shipowners will only do this if over a 4–5-year period it will reduce their operating costs from having invested in the installations versus the cost of a crew.

Appendix 3 Questionnaire on Remotely Controlled Shipping Communications

Questionnaire on Remotely Controlled Shipping Communications

Conducted From 1 April 2022 to 1 May 2022

The IMO's Maritime Safety Committee approved the framework and methodology for the regulatory scoping exercise on Maritime Autonomous Surface Ships (MASS) during its 100th session held on December 3-7, 2018.

A MASS has been defined as a ship which, to a varying degree, can operate independently of human interaction.

For the purposes of this questionnaire, MASS degree two and degree three should be considered for Sea Areas A1, A2 and A3.

- Degree two: Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.

- Degree three: Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.

* Required

1. Please provide a brief description of your field of work, job title or role and years of relevant experience. *

   NOTE: All Responses and Information Will be Anonymised.

2. Has the subject of remotely controlled shipping communications been considered or discussed within your organization? *

- ○ Yes
- ○ No

3. What level of consideration has been undertaken? *

- ☐ Informal discussions only
- ☐ Formal consideration relating to regulatory amendments
- ☐ Regulatory amendments have taken place to accommodate remote vessel operations
- ☐ Operation or testing of remotely operated vessels has taken place

4. In terms of maritime communications, rate the challenges to future remote shipping operations? *

1-Minor Barrier 2-Standard Development Challenge 3-Major Barrier

	1	2	3
Regulatory Challenges	○	○	○
Technical Challenges	○	○	○
Cost of Implementation	○	○	○
Industry Acceptance	○	○	○

5. Do you consider it necessary for remotely controlled vessels to interact with existing maritime communication systems and procedures? *

e.g. GMDSS, AIS etc.

- ◯ Yes
- ◯ Partially comply and interact with existing mandatory communications regulatory requirements
- ◯ No

6. What extent should remotely controlled vessels comply with and be capable of interacting with existing maritime communication system requirements and procedures? *

	Not Required	Required to Meet Existing Standards	Meet Existing Installation Requirements with Performance Standards Modified for Remote Functionality	Exceed Existing Installation Requirements. Performance Standards Modified for Remote Functionality Increased System Redundancy and Duplication.
VHF Voice & DSC Communications (GMDSS)	◯	◯	◯	◯
MF/HF Voice & DSC Communications (GMDSS)	◯	◯	◯	◯
Receive and Send Maritime Safety Information Messages	◯	◯	◯	◯

Receive GMDSS Distress Alerts	○	○	○	○
Transmit Search and Rescue Locating Signals (SART/AIS-SART)	○	○	○	○
Transmit and Receive Search and Rescue Locating Signals (SART/AIS-SART)	○	○	○	○
Approved GMDSS Satellite Facility	○	○	○	○
Automatic Identification System (AIS)	○	○	○	○
Long Range Identification and Tracking (LRIT)	○	○	○	○
Ship Security Alert Systems (SSAS)	○	○	○	○
Global Navigation Satellite System (GNSS) Receiver	○	○	○	○

7. Remote control/monitoring of the navigation, engineering, vessel safety and cargo functions present a significant additional communication data burden.

   Current proposals to meet remote vessel high bandwidth communication requirements are based on open commercial networks. e.g. VSAT, mobile phone networks etc.

   Is it acceptable for vessel critical systems to rely on such open networks? *

   - ◯ Yes, use of and reliance on open commercial networks/systems is acceptable.
   - ◯ No, use of and reliance on open commercial networks/systems is not acceptable.
   - ◯ The use of open commercial networks in conjunction with established communication systems is acceptable

8. In locations with limited communication coverage; is it acceptable for critical ship monitoring systems to operate at reduced capability, where there is lower vessel traffic density and navigational hazards? *

   e.g. Open ocean transit

   - ◯ Yes
   - ◯ No
   - ◯ Partially reduced monitoring is acceptable

9. Where communication capabilities are reduced; describe examples of acceptable reductions in monitoring of critical ship systems? *

   e.g. Reduced sensor reporting, cameras quality/availability in areas of low vessel traffic density and navigational hazards.

10. Do you have experience with maritime or communications regulatory development? *

e.g. Input or attendance at relevant National legislative bodies, IMO, EU, ITU meetings etc.

- ◯ Yes
- ◯ No

11. In terms of regulatory development, which organisations do you have experience with? *

- ☐ National legislative body
- ☐ IMO
- ☐ ITU
- ☐ EU
- ☐ CEPT
- ☐ ETSI
- ☐ IMSO
- ☐ Other

12. Based on your experience of contributing to the development of regulations, what are the key processes within the various organisations that must be completed for the implementation of globally harmonised MASS communications to be achieved? *

e.g. IMO, ITU procedures and process which must be followed

13. What do you consider to be a realistic timeline for the implementation of necessary international maritime/communications regulations to facilitate the operation of remote shipping? *

- 1-5 Years
- 5-10 Years
- 15-25 Years
- I do not foresee the development of international maritime communications regulations to facilitate the operation of remote shipping