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Uncrewed Vessel Port Entry

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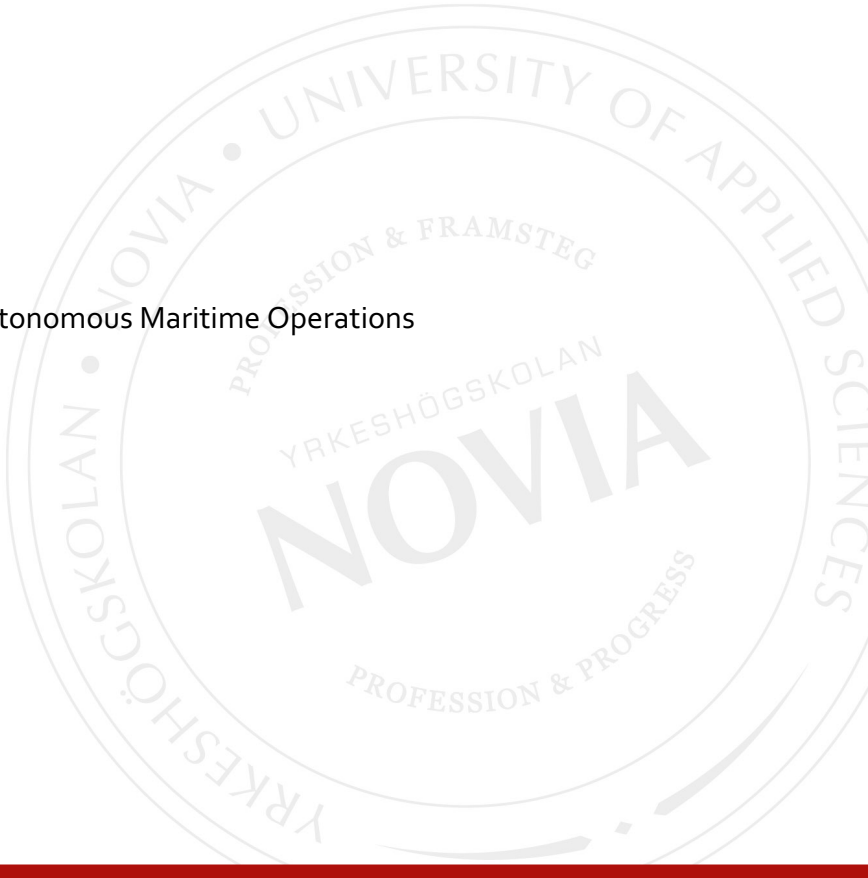

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Abstract

The aim of this thesis was to determine the obstacles to autonomous and remotely controlled ships operating in port areas in Ireland, in particular arrival and departure from ports. This was examined from the perspective of the ports regarding pilotage and control of traffic/interaction with other traffic. The secondary aim was to determine what measures ports may have to put in place to facilitate the operation of these vessels.

Interviews were conducted with Harbour Masters, Marine Pilots and vessel traffic service operators. The interviewees were drawn from a mix of large commercial ports, fisheries harbours and leisure harbours including ports with and without vessel traffic services. The interviews were semi structured and open to allow participants to explore the potential difficulties and additional requirements port operators may have to facilitate this new technology. The interviews were then coded and analysed to extract the key findings.

The study found that ports expect autonomous and remote-control vessels could safely operate in port areas subject to some safety concerns which would require addressing. It was found that a wide dissemination of information is required to build awareness among port users of these vessels and that specific identifying lights and shapes should be considered internationally. The area of most concern to the participants of this study was in relation to communications between the ports, pilots, conventional vessels and remote-control/autonomous vessels. This concern was wide ranging and covered methodology, standardization and compatibility bandwidth availability for large data transfers. Another concern was latency in communications where urgent time sensitive decisions and security of communications were required to avoid confusion or malicious actions. These communication protocols were considered urgent as investments may be required in ports to facilitate operations.

Language: English Key words: Uncrewed, MASS, Ships, Ports, Pilotage

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1 Introduction

The testing of autonomous and remote-control vessels, or to use the term adopted by the International Maritime Organization (IMO), Maritime Autonomous Surface Ships (MASS), is advancing around the world in many test areas and by a number of companies.

The two biggest topics currently in the maritime world are emissions from ships and autonomous maritime operations, and indeed both topics are linked as many see automation as being a driver for reduced emissions. The main driver for developments in the industry will be the financial benefits for the owner which may become greater as ports and states look to reward green operators.

A cost benefit analysis has been carried out which looked at the current savings made over the lifetime of a conventional bulk carrier compared to an autonomous bulk carrier (Kretschmann, L., Burmeister, H.-C. and Jahn, C. 2017). They found that the savings over 25 years for the owner was US$ 4.3 million and the freight rate for chartering the ship to carry a cargo would be 3.4% lower than for a conventional manned bulk carrier.

The main drivers for these savings are crew costs and benefits from a reduction in fuel use. The fuel reduction is based on differing ship design and reduced weight of the ship as it will not require accommodation for crew, fresh water, air conditioning plant and all the other services that are required for humans on board a ship. Some operators put the cost of crewing at 60% of their operating costs (Lloyd's List, 2018). This is particularly the case in the tanker sector or the passenger ship sector, where more specialized crew are required in greater numbers.

There are considerable difficulties in overcoming the making of autonomous shipping a reality both from a regulatory perspective and a technical perspective. Another issue is the question as to whether ship owners want this technology.

The appetite for removing crew in this area is very limited on some ship types. On passenger ships there may not be acceptance from a regulatory point of view. Additionally, from an operating company point of view they know that crew are required to look after their guests safely. Research has found that passengers are significantly less willing to ride onboard autonomous cruise-ships, Mehta, R., Winter, S. R., Rice, S., & Edwards, M. (2021).

This is also the case on tankers where the consequences of an accident are enormous both financial and environmentally. There are additional concerns with such a high value asset and cargo, most owners would choose to have their representatives on location. In an analysis on the safety impact of making ships autonomous, it was found that making very large ships autonomous only had a very minor effect on safety at sea (De Vos, J., Hekkenberg, R. G., & Valdez Banda, O. A. (2021). There may be benefits for these types of vessels as a result of research and innovation in navigation and emergency decision support systems.

The other major difficulty, due to the early stage of the autonomous sector, is that there are no systems yet (at least in the public domain and approved by a flag administration) that can navigate safely and in full compliance with current regulations. The International Maritime Organization has undertaken a scoping exercise covering some of the IMO conventions to establish what regulations may pose a barrier to the operation of autonomous ships (IMO, 2021).

Before regulatory authorities, ship owners and general public accept the general use of remote-control vessels, they must ensure that there is no greater risk in the remote operation of vessels compared to conventionally operated vessels with crew on board maintaining a watch and must be able to safely interact with conventional users of the maritime space.

Lost in the excitement of industry commentators on the subject of autonomous ship operations is the fact that the area where we are most likely to see and indeed are already seeing operations being conducted is by remote control rather than autonomously.

The testing and indeed the operation of autonomous and remote-control vessels, or to use the term adopted by the International Maritime Organization (IMO), Maritime Autonomous Surface Ships (MASS), is advancing around the world in many test areas and by a number of companies.

It is important to understand the levels of autonomy that are being considered. The IMO has defined four degrees of autonomy as follows:

> **Degree one**: Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.

> **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.
>
> **Degree four**: Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself. (International Maritime Organization, 2022)

The first step of the IMO scoping exercise has been completed. The next step which is now underway is to analyse and determine the most appropriate way of addressing MASS operations withing the international legal framework.

Degree three is the area where most development has taken place and several companies are already operating these types of vessels under domestic law arrangements while countries await changes to international conventions.

There is already considerable use of small remote-control vessels mainly engaged in seabed surveys, fish stack surveys, and inspection of pipelines and underwater infrastructure for the oil industry. Another novel use of these vessels is to use them for uploading data from sub-sea monitoring devices such as the ones used by oil companies to monitor the level of the seabed to give them warning of any risk of subsidence due to oil or gas extraction.

It should also be noted that autonomous navigation systems and systems that can make decisions which comply with the requirements of the International Regulations for Preventing Collisions at Sea (COLREGs, 2003) are quite different. The former is currently possible, and the latter is something that has yet to be demonstrated as compliant with the COLREGs. The COLREGs are quite complicated for machines to comply with for two reasons: First, as they are written with the assumption that a human is interpreting them. The human watchkeeper will take decisions in weighing up the appropriate action to take based on their knowledge of the rules. Second, different rules apply to vessels in sight of one another or in restricted visibility which can also be difficult for a computer algorithm to assess.

There are several questions that need to be addressed before remote control operations can occur in port areas and areas of high-density traffic or in areas with more complicated navigation. Among the issues which may cause difficulties are how will the vessel communicate with the port authorities and receive instructions. There is also the possibility that autonomous traffic may need to be separated from conventional traffic or if perhaps separate port facilities or autonomous hubs may be required.

Proponents of these new technologies will need to find workable solutions that will satisfy port and national authorities as well as the public so that these disruptive technologies can meet the requirements of regulators and seamlessly and safely interact with conventional vessels. It is important that maritime leisure users continue to enjoy the freedoms which they currently enjoy.

It should also be remembered that leisure users may not have methods of electronic identification such as Automatic Identification System (AIS). In fact, leisure users such as those in small boats, kayaks, canoes, surfboards and indeed swimmers may not even be easy to detect using camera/visual technology.

The navigation of these vessels from one location to another is possible with currently available technology, if we ignore the difficulty machines may have in reading and understanding navigation charts and other navigation information which is designed for the human operator. These operators also have difficulty in complying with international conventions as they are currently written or understood.

Limited studies have been carried out assessing how these vessels will fit in the world of manned vessels, in particular dealing with when they will have to make an approach to and navigate within a busy port with additional traffic and restricted/controlled space (Gu, Góez, Guajardo & Wallace, 2019).

There are a number of questions that need to be addressed before autonomous operations can occur in port areas. Among the issues which may cause difficulties are how will the vessel communicate with the port authorities and receive instructions, will the vessel require a harbour pilot, will autonomous traffic need to be separated from conventional traffic, will separate port facilities or autonomous hubs be required. There may be a requirement for at sea maintenance hubs with drone support.

Proponents of these new technologies will need to find workable solutions that will satisfy port and maritime regulatory authorities' concerns that the operation of these new vessels can be conducted safely. The public will need to be able to have trust that these disruptive technologies can meet the requirements of regulators and seamlessly interact with what are now conventional vessels safely without disrupting other vessels operations and still allow the maritime leisure users to enjoy the freedoms which they currently enjoy.

The aim of the project was to determine the obstacles to autonomous and remotely controlled ships operating in port areas, in particular arrival and departure from ports from the perspective of the port with regard to pilotage and control of traffic/interaction with other traffic and to determine what measures ports may have to put in place to facilitate the operation of these vessels.

This paper looked at the Irish context where there have not yet been any trials of autonomous or remote-control vessels. This work has researched the issue from the perspective of ports to determine what level of understanding of the subject exists. This research also considers what requirements ports may put in place to permit these types of operations in their areas of control. Where this paper refers to remote-control or autonomous vessels, this is in the context of the vessels being uncrewed.

Ireland has not currently implemented a national Vessel Traffic Service (VTS), only one port in Ireland has a declared port VTS. However, other Irish ports do have vessel monitoring systems established. To contribute to this thesis, interviews have been conducted with Harbour Masters, Pilots and VTS operators in Ireland. A variety of port types were selected including large commercial ports, fisheries harbours and ports that are primarily used by leisure vessels.

Past introductions of new technology on ships such as radar have reduced costs for ports, allowed for reduced pilotage area and made national news (Radio Teilifis Eireann, 1962).

1.1 Problem Formulation - Research problem

The primary aim of this thesis was to look at the operation of autonomous or remote-control vessels in port areas. Most of the research into this area involves the conduct of voyages at sea and the automation of methods of compliance with the International Regulations for the Prevention of Collisions at Sea (COLREGs) (IMO, 2003).

There is a limited body of research into these operations (Gu et al, 2019) in the most critical phase of a ships' voyage, in their comprehensive study of the issue. This phase of the voyage generally has shallower water, higher density of traffic, reduced sea room for manoeuvring and greater risk to the marine environment in the event of a collision or grounding. From a legal research perspective, while it is an emerging area of research interest, there is not yet widespread publication of findings (Ringbom, Røsæg & Solvang, 2021).

These traffic areas are also generally under the control of a port or pilotage authority and may have their own port specific rules and regulations due to the unique nature of each port and differing limitations within the area due to bathymetry or tide among other issues.

Traffic in most busy ports has been regulated for hundreds of years with some vessels being required to carry a pilot with local knowledge to advise the ship on entering port and others receiving instructions on entry and route, One example was the level of traffic and the need for regulation on the river Thames, as was apparent in the 14th century which led to the introduction of regulations for pilotage in 1514 with the granting of a royal charter to Trinity House by King Henry VIII (Port of London Authority, 2019), another example was the Irish Port of Limerick (now known as Shannon Foynes port), which was granted the power to regulate pilotage in 1815 (Shannon Foynes Port Company, 2019).

The methods of communications at that time were basic, utilizing methods such as hoisting an appropriate flag signal to request a pilot or entry. A pilot station could then signal a reply followed by a pilot boarding the ship. A pilot would prove their credentials by producing their pilot warrant issued by the pilotage authority.

Currently, ports will generally have received information about the arrival of ships days if not weeks in advance. There will generally be a requirement for ships over a determined length to carry a pilot to advise the ships master.

On the approach to a port, ships will make contact with the port traffic control centre by VHF radio and will receive instruction about time of entry, about what vessel will go ahead of them, about what time pilot will be on board, about what part of the port the ship will berth and about other relevant information.

The port will monitor the ships in its area using a combination of Radar and Automatic Identification System (AIS). In general, all communications and instructions will be by voice

over VHF radio. Once the pilot is on board instructions will be relayed verbally by the pilot on board to the ships master and bridge team.

If autonomous and remote-control vessels are to be accepted operating into ports, then they must demonstrate that they can safely enter port and safely interact with other vessels and actors within a port area and follow the instructions of the ports' vessel traffic service (if one is operating) which controls the space. It is also worth noting that a port will almost certainly have leisure users and possibly people swimming in the area.

Among the questions that I intend to consider concerns pilotage if the port requires it. It is usual that a pilot on board is required by visiting vessels which are over a designated size. In the future in relation to MASS vessels ports could carry out remote pilotage, perhaps by communication with the autonomous vessels control centre.

Another question looked at is will separate traffic lanes will be required, will vessel signals/lights to identify them be required and will autonomous vessels be required to berth in a separate part of the port facility away from other traffic.

It should be noted that most test areas for autonomous and remote-control vessels are located away from port areas and busy traffic areas. It would be expected that this would need to change as technology and testing develops to allow for the building of trust with the public, regulators, and conventional shipping in mixed traffic situations.

1.2 Research Aim

The purpose of this thesis is to ascertain an overview of the major barriers and essential operational safety measures which must be addressed within Irish ports to facilitate autonomous and remote-control vessel operations. This research will consider and establish the expert views of port navigation operational managers. The thesis is limited in its scope to Irish ports. The expert participants will have been predominantly derived from experienced Harbour Masters, Pilots and VTS operatives from various major ports, and smaller regional harbour throughout Ireland.

This interview-based research will examine the current views and knowledge of relevant industry expert decision makers in relation to the subject of autonomous and remote-control

vessels. These interviews from industry experts will seek to gain an insight into the level of awareness of these key industry policy influencers, in relations to the potential for autonomous operations within Irish ports.

Based on this work, an understanding of the fundamental requirements which industry experts consider essential for in-service testing of autonomous and remote operations will be derived. The potential challenges of autonomous and remote vessel operations in smaller ports will also be considered. Such operations and testing in smaller regional ports may present additional unique localised obstacles, as smaller ports and harbours generally do not have VTS systems to monitor and control the navigation areas.

This work will consider and identify the specific factors which need to be addressed for the operation of Maritime autonomous surface Ships (MASS) to be permitted. This will include an attempt to ascertain the additional safety factors which port authorities may require to increase and develop their trust in autonomous and remote technologies, particularly in high traffic density areas with multiple vessel types in a safe manner may be facilitated.

In addition, this work may provide national policy makers and regulators, with an academic based insight into the safety concerns which port authorities consider essential in terms of autonomous and remote operations. This may contribute and inform national regulatory and legislative development in the area of autonomous and remote vessel operations.

In order to achieve the aims of this broad and complex technical topic, further information is required from relevant maritime experts. The following questions should be further understood within the context of pilotage operations within Irish ports and harbours:

- Is the operation of autonomous or remote-control vessels within port areas or approaches under discussion within relevant organisations?
- What are the expert views on how pilotage could be conducted on remote controlled or autonomous vessels?
- How do experts see communications taking place between autonomous or remote vessels in relation to instructions from the port authorities and communications with pilots, tugs and other vessels?
- Do experts think that remote/autonomous vessels can safely interact with other traffic in port areas?

- Is there a need in the view of experts for different requirements for smaller autonomous/remote vessels as opposed to larger autonomous/remote control vessels?
- Do experts see a need for measures to separate remote/autonomous vessels from conventional manned vessels?
- What additional safety measures, if any would experts propose for the operation of autonomous or remote-control vessels within port areas or approaches?

1.3 Research Problem

To fulfil the aim of this thesis, the following broad topics need to be addressed:

Issues relating to the conducting of pilotage operations on autonomous and remote-control vessels, and how ports can safely carry out the essential task of pilotage services on unmanned vessels needs careful consideration. The majority of commercial ports in Ireland have long established pilotage requirements. Any transition to autonomous or remote vessel operations will have a fundamental impact on how these pilotage operations are undertaken. Therefore, all aspects of these tasks need to be fully addressed.

The issue of how communications will take place between port authorities and autonomous or remotely controlled vessels requires full consideration. Communications challenges need to be addressed within port and VTS areas so that port authorities can maintain control of all vessel traffic and effectively communicate information and directions to all ships, including autonomous or remotely controlled vessels. Vessel communications are coordinated and harmonised by the International Telecommunication Union (ITU). ITU is the United Nations specialized agency for information and communication technologies. The Global Maritime Distress and Safety System (GMDSS) is an internationally agreed set of safety procedures, frequencies, types of equipment, and communication protocols, developed through cooperation between the International Maritime Organisation (IMO) and ITU. It operates using terrestrial and satellite radio technologies on board ships and onshore. The technologies and procedures used by shipping as part of the GMDSS are essential to inter-ship and ship-to-shore communications. These technologies and standards are also relied

upon for vessel traffic management. Therefore, the interaction of autonomous or remotely controlled vessels with established technologies must be studied in detail and harmonised on an international basis.

Consideration must be given to the potential need to separate autonomous and remote-control vessels from conventional vessel and other maritime traffic. There may also be a need to establish if small autonomous and or remotely operated craft should be treated differently to larger size autonomous or remotely vessels.

Consideration must also be given to ascertain if any additional safety procedures would be required by ports to allow autonomous and remote-control vessels to enter their areas of responsibility and jurisdiction.

2 Literature Review and Theory

2.1 Pilotage Areas

In open seas, the Master of a ship has discretion over the movement of his or her vessel, so long as the ship remains in compliance with international instruments, such as United Nations Convention on the Law of the Sea (UNCLOS) and COLREGs. In general, at sea there are no restrictions on where the Ships Master navigates their ship once the conduct is in compliance with the International Regulations for the preventions of collisions at sea and the right of freedom of navigation and innocent passage is protected under the UNCLOS (United Nations, 1982). Any changes that may be required to UNCLOS to facilitate uncrewed vessel operation is complicated to achieve and the process has not been utilised to date (Chircop, A. 2018).

The operation and overall conduct of the navigation of a ship complicated within the jurisdiction of port authorities, pilotage and VTS areas. This is due in general to the limitations of operating in confined waters. In addition, the control of the ship is under the direct influence or instruction from an outside party e.g., a pilot, port or VTS authority may direct ship movements by issuing directions to the Master.

There are national legislative provisions for traffic routeing measures to facilitate the safe navigation of all vessels. This includes the establishment of ship traffic lanes which are implemented in areas where a coastal state determines that they are required for the purposes of safety of navigation (IMO, 2022).

Unlike air traffic control, where aircraft are monitored and their movements regulated through international coordination, there are no systems in place at sea for the control of ships outside coastal jurisdictions. The control of the movement of ships is also different in port and pilotage areas. In such confined areas, the port or coastal state controls the space. However, this control is limited and relates to the general direction of movement of the ship i.e., ship directions are generally nonspecific and advisory. In this regard, the control of ship movement is the complete responsibility of the Master. In case of pilotage operations, the pilot is on board the ship in an advisory capacity based on the knowledge of the port area. Therefore, in legal terms, a pilot is considered as being on board to provide advice, whilst the Master remains responsible for the ship and its operation including movements.

The conduct of ship pilotage operations is routine for conventional ships. In general, a ship provides appropriate notice to the port or pilotage authority and the ship embarks a local pilot on arrival at a specified location and time. The local pilot is considered an expert in local waters and their navigation (Tuisku Salonen, Mikael Wahlström, Hannu Karvonen, 2020).

The local pilot will provide advice to the Master on local requirements and navigation in the area, they will be an expert on the navigation of the area concerned including its tides and shallow areas. The pilot will also deal with communications with the port and instructions to the master on the movement of their vessel within the space, additionally they will act as the communications link with other ships, harbour tugs, mooring teams, terminals, and other actors in the port and provide considerable support to the ships Master with their expertise and local knowledge, including local language skills.

Some ports have made provisions for ships' master's which make regular calls to that port to be exempt from the requirement to carry a pilot. To obtain a port Pilotage exemption certificate, the Master must be completely familiar with the port and undertake an examination. The most common criteria for compulsory pilotage is >500GT or greater than 70 metres LOA. However, it is the case that there are many variables from port to port (European Commission, 2012)

Pilotage operations happen in real time with no delay in passing information and guidance to the ships Master. In terms of potential autonomous or remotely controlled and their interaction during pilotage operations, a major question obstacle may be the development of robust method of communicating instructions to the vessel. A study on non-technical communications in vessel traffic services found that the ship and shore can have differing perceptions of reality. The study found that it is easier for master or pilot of the vessel to predict some movements or events. (Costa, N. A., Lundh, M., & MacKinnon, S. N. (2017). Communications during pilotage operations may be further complicated if a vessel is reliant upon a remote operation centre. Any communications latency issues may cause delays in safety critical decision-making during pilotage operations. Such communications and associated procedures must be considered and addressed.

2.2 Pilotage and legal issues

When ships are trading internationally, the passage is conducted under the direction of the ship's Master in accordance with various international conventions and instruments. From a commercial perspective, the ship owners and charterers issue operational instructions which direct vessel overall operations and trade routes. Legal complexities generally arise during the port and confined area of operations of ships, not in the open sea. Therefore, there is a high burden of responsibility on port authorities. This includes the consideration of all legal consequences for vessels operating within their ports. In a study on the indispensability of pilotage services, the author was of the view that to undertake a transit in compulsory pilotage waters, there had to a concord between the pilot and the ship master on the acceptability of the planned transit and that neither should move without the other (Arum, E. (2018).

In terms of pilotage operations, there is no international convention covering this area. Pilotage operations are complex from a legal perspective as each area is subject to their own national legislation. From an Irish perspective, pilotage operations requirements are detailed in legislation (Harbours Act 1996). This Act sets out provisions in relation to the management, control, operation and development of ports and harbours in Ireland and the law relating to pilotage and confers the legal functions in relation to pilotage within Ireland. The Act also includes important legal provisions in relation to organisation and provision of pilotage services in Irish ports.

This Harbours Act 1996 provides local port and harbours with the legal authority to regulate and establish mandatory pilotage requirements at a local level. This may mean, that each port or harbour may present different pilotage requirements which need to be separately addressed to facilitate autonomous or remote operations. For example, Dublin Port is subject to specific local byelaws which are set down in the Dublin Port Company Pilotage Byelaws 2020. This fourteen-page legal document sets out the compulsory pilotage requirements which are applicable to all ships which visit Dublin Port.

In a recent publication on Autonomous Ships and the Law (Henrik Ringbom, Røsæg and Trond Solvang, 2021), the view is taken that pilotage regulation may be a profound legal obstacle to the operation of autonomous or remote-controlled vessels. This view is taken due the variety of local pilotage regulations in different national jurisdictions and between ports within the same jurisdiction. As with the example of the Dublin Port Pilotage Byelaws, local regulations often vary and are mandated by local authorities i.e., not at a consistent national level.

If a port has a legal requirement to have pilotage, a new way of conducting pilotage operations may need to be legislated for by the authorities involved. It is likely that any legal changes will be required at both a local and national level.

2.3 Pilotage and Communications

Currently to operate in a port or pilotage area the ability to communicate instructions and responses between the port, individual vessels or vessel traffic service is essential to operations. In particular in ports with narrow areas where ships may not be able to meet or when nearing bends or obstructions and they have to communicate with each other to coordinate movements.

Communications between all actors in port operations becomes more difficult when there is not a person on board to communicate with. If a port has to have a message relayed to a remote operations centre or make direct contact with them without delays or confusion, the question arises as to how this will take place and what technology will be required, these are questions that will need to be answered along with the availability of reliant bandwidth to transmit data.

There is a risk that where remote or autonomous vessels are operating in ports that the communication between them and conventional vessels to facilitate safe traffic movement and organisation will be one sided until internationally agreed communication protocols are in place which could lead to wrong decision making during the transition to MASS vessels (Zhou, Y. & Bellsola Olba, X., 2018).

Latency in communications or data may cause problems in real time decision making at critical times if the data being observed is not a duplicate of the real time scenario on the water.

When considering vessels operating autonomously, this becomes more complicated as if there is no control centre involved, a port will have to communicate with a machine in a standard format that is readily available (Charting Regulatory Frameworks for Maritime Autonomous Surface Ship Testing, Pilots, and Commercial Deployments, 2020).

The coordination, dissemination of information and passing urgent instructions to a remote control or autonomous vessel can pose further difficulties in countries like Ireland with no national vessel traffic service and where only one port has a port vessel traffic service. The key link for carrying out this function in these areas is the vessels pilot, which will become more complicated without a pilot on board and no VTS to fill the coordination role.

3 Methodology Description and Implementation

3.1 Research Theory

The author used a grounded theory approach to the qualitative study. This method was adopted to allow the participants views to come to the forefront and drive the direction of the of the emerging theory. This method was also considered preferable as it had the potential to avoid directing the conversation and introducing bias on the part of the author.

In their publication on conducting research (Charmaz, 1991), described the benefits of intensive interviews, which can often be a one-sided conversation if conducted appropriately. By beginning with broad open-ended questions which explore the researcher's topic and fits with the interviewees experience, unanticipated views may come to the fore. This approach also attempts to avoid unintended prompting during interview. It may also promote further questions by avoiding an interrogation style of interview.

A constructionist approach and analysis were applied to the collated participant responses. This method meant that the thoughts and views of interviewees were allowed to come to the forefront and influence the emerging codes. Charmaz, 2014, considers that coding is the pivotal link between the data that you are collecting and the theory that emerges from it, using the coding you define what is happening within the data and begin to consider what it means.

Semi-structured interviews were carried out with the participants, who were all maritime professionals and a mix of Harbour Master/Port Operations Manager, Pilots and Vessel Traffic Management operators. One participant was from outside Ireland due to the lack of a national vessel traffic service in Ireland and a desire to get views from a person with experience in this area.

Interviews were initially planned to be conducted face to face, however this plan had to be revised as it was not possible due to the arrival of the Covid pandemic in 2020.

Following an appraisal of suitable options to proceed with the interviews it was decided to use online video facilities to conduct the interviews, these were recorded with the agreement of the participants for the purpose of transcribing the interviews.

Meetings were arranged with the interviewees with sufficient time allotted to allow for an unhurried interview which allowed the participant to take the discussion in whatever direction they wished to with their views and expand on the areas that they felt more strongly about. All were advised that the recording would be deleted,

A total of 13 interviews were conducted which was considered a suitable number to make determinations from the interview transcripts. Bryan Marshall, Peter Cardon, Amit Poddar & Renee Fontenot (2013), in their study of interview numbers in 83 different qualitative studies, describe how in terms of thematic code prevalence, saturation point was generally reached within 12 interviews and at that point data saturation was achieved with few new themes emerging past that point. There was no standard number of interviews that were found desirable to be carried out. In their publication (Saunders, 2012), describe the process of reaching saturation in grounded theory research as being driven by the data and what categories are emerging from the analysis as you conduct the interviews and start observing the direction emerging and the codes emerging, once no new categories are emerging you have reached saturation. This makes the selection of interviewees particularly important.

The choice of semi-structured interview was to reduce as much as possible and interviewer bias and to ensure that there was no unintentional steering of the interviewees in any direction or even suggesting possible outcomes. The questions were designed to be inductive in nature and to let the opinions of the interviewees drive the outcome. The main purpose of this method was to try and avoid any bias from the author and minimize inbuilt bias brought in due to the author having chosen the questions. It was hoped that this method would enable issues that had not been previously considered to emerge in this research.

3.2 Research Process Implementation

The permission of interviewees was sought, and the use of the data was fully explained to all participants. Each participant was advised that their views may be quoted, and their names used. They were also advised that they could withdraw permission subsequently if after the interview they formed the view that they no longer wished to participate. Participants were given the option to remain anonymous if required, one interviewee wished to remain unnamed. All interviews were given on the basis that they were personal professional opinions and did not reflect or represent the views of their employers or organizations.

Once the interviews had taken place, they were transcribed to enable coding and analysis of the data obtained from the interviews. All recordings will be deleted on completion of thesis and with the agreement of the thesis supervisor.

The transcripts were then inputted into a Quirkos qualitative data analysis tool to assist in breaking down the interviews line by line to analyse what themes were emerging from the interviews and to develop codes based on the emerging views of the interviewees. Quirkos is a software tool that tries to make coding as quick and easy as possible, this is achieved by allowing you take interview quotes and categorize then into your chosen themes (Quirkos, 2022). This process was repeated and refined several times and quotations from the interviewees were coded as appropriate using the codes that had emerged from the interviews.

All participants in the study are expert maritime professionals with extensive experience, both onshore in port or harbour management, and previous seagoing experience. All

participants agreed to the publication of their comments, one participant chose to remain anonymous.

3.3 Details of Interview Participants

The named participants are listed below in alphabetical order, giving background and information on each participant:

Table 1. Participants

Participant Name	Bourke, Nicholas
Current Maritime Industry Role	Deputy Harbour Master Port of Cork
Current Area of Responsibility	The Port of Cork is the world's second largest natural harbour and is a key international gateway for trade. The key seaport in the south of Ireland, it is one of only two ports in Ireland to service all six shipping modes - lift on/ lift off, roll on/ roll off, liquid bulk, dry bulk, break bulk and cruise. The Port of Cork Company is a commercial semi-state company responsible for the broad range of commercial running of Cork harbour as well as the navigation and berthage in the port. https://www.portofcork.ie/

Participant Name	Coate, Simon
Current Maritime Industry Role	Dún Laoghaire Harbour
Current Area of Responsibility	Dún Laoghaire Harbour is a 200+ year old Victorian port located 12km south of Dublin's City Centre, in the town of Dún Laoghaire. https://dlharbour.ie/ It is under the ownership of Dún Laoghaire-Rathdown County Council https://www.dlrcoco.ie/en

Participant Name	Collins, Nigel
Current Maritime Industry Role	Dingle Harbour Master
Current Area of Responsibility	Dingle harbour is managed and operated by the State to promote sea fishing and related industries as well as other economic and social development including leisure facilities. https://www.gov.ie/en/publication/be00f-fishery-harbours/

Participant Name	Donnelly, Martin
Current Maritime Industry Role	Drogheda Port Company Harbour Master and Chief of Operations
Current Area of Responsibility	Drogheda Port Company is a highly successful commercial state port which handles over 1 million tonnes of cargo annually in addition to over 700 vessel calls. The Company provides port facilities for both general freight and container services and has a record of continuous growth in both. The Port has a wide product base and a balance of trade at approximately 75% import and 25% export. We are a natural choice for a wide range of customers and trades, with facilities to handle virtually any type of cargo. http://www.droghedaport.ie/

Participant Name	Doyle, Darren
Current Maritime Industry Role	Harbour Master Port of Waterford
Current Area of Responsibility	The Port of Waterford is Ireland's closest multi-modal port to continental Europe, is connected by road and rail to a national transport system that can get goods to their destination in a prompt and efficient manner. https://www.portofwaterford.com/

Participant Name	Finseth, Kim Stinessen
Current Maritime Industry Role	VTS Operator
Current Area of Responsibility	VTS operations within the Norwegian Coastal Administration is a transport agency under the Ministry of Trade, Industry and Fisheries. We ensure safe and efficient traffic in fairways and into ports, and a national preparedness against acute pollution.

Participant Name	Lane, Deirdre
Current Maritime Industry Role	Dunmore East Harbour Master
Current Area of Responsibility	Dunmore East is a major fishing port situated at the south end of Dunmore Bay, on the west side of the entrance to Waterford Harbour. The harbour is well sheltered, although subject to a considerable swell at HW in gales from SE. Depth in the entrance is 2.6 metres and in the harbour 2 metres to 3.6 metres. Crowded

	during the autumn herring season. https://www.gov.ie/en/publication/be00f-fishery-harbours/
Participant Name	Murphy, Phil
Current Maritime Industry Role	Wexford County Harbour Master/Senior Marine Officer
Current Area of Responsibility	Wexford County Council is the authority responsible for local government in County Wexford. https://www.wexfordcoco.ie/

Participant Name	O'Regan, Paul
Current Maritime Industry Role	Harbour Master and Chief Operations Officer Port of Cork
Current Area of Responsibility	The Port of Cork is the world's second largest natural harbour and is a key international gateway for trade. The key seaport in the south of Ireland, it is one of only two ports in Ireland to service all six shipping modes - lift on/ lift off, roll on/ roll off, liquid bulk, dry bulk, break bulk and cruise. The Port of Cork Company is a commercial semi-state company responsible for the broad range of commercial running of Cork harbour as well as the navigation and berthage in the port. https://www.portofcork.ie/

Participant Name	Power, Bernard
Current Maritime Industry Role	Marine Pilot Dublin Port
Current Area of Responsibility	Dublin Port is Ireland's premier port, handling almost 50% of all trade in Ireland. https://www.dublinport.ie/

Participant Name	Russell, Mark
Current Maritime Industry Role	Marine Pilot Dublin Port
Current Area of Responsibility	Dublin Port is Ireland's premier port, handling almost 50% of all trade in Ireland. https://www.dublinport.ie/

Participant Name	Sheridan, Brian
Current Maritime Industry Role	Harbour Master Port of Galway
Current Area of Responsibility	The Port of Galway is situated at the centre of Galway City. It has a history dating back to the 10th century, serving the city and region. The Port Company set out to develop a new Port for Galway, allowing larger ships to moor alongside this new infrastructure and by doing so, remove the commercial shipping and its associated activities out of the existing "gated" harbour. https://theportofgalway.ie/

3.4 Research Questions

The research questions were chosen to open the discussion in various areas and to encourage the interviewees to give wide ranging answers from their professional expertise in the maritime domain. The interviewees chosen were all people who have positions where they are responsible for the operational safety of ships in port areas.

The aim of the questions was to extract views from the interviewees on how they would anticipate remote and autonomous operations happening in the port that they are responsible for as they are the ones that currently manage the safety of conventional vessels and would have to manage the ae operation of vessels utilizing new technologies using their ports. They are in the unique position to be able to give their experienced views of what steps must be taken to satisfy their safety requirements and be in a position to accept the safety case for MASS operations. The following table contains a list of questions that were posed to each of the participants during the interviews and the reason/rational for each question:

Table 2. Interview Questions

Interview Question	**Rational for asking the Question**
Has the operation of autonomous or remote-control vessels within port areas or approaches been discussed within your organisation?	To ascertain if participants have undertaken formal discussions on autonomous of remotely controlled shipping operations. In addition, to understand if the subject is under broader discussion within the Irish maritime industry among port authorities.
How would pilotage be conducted on remote controlled or autonomous vessels?	To gain an understanding of how port authority experts perceive the requirements for autonomous of remotely controlled shipping operations within Irish ports.
How would communications take place with such vessels in relation to instructions from the port authority and communications with pilots, other vessels, tugs?	To understand the extent to which port authorities see the requirement for remote shipping operations to interact with existing maritime systems and procedures in terms of communications.
Could remote/autonomous vessels safely interact with other traffic in port areas?	To ascertain the challenges perceived by port authorities to remote shipping operations taking place in Ireland in conjunction with existing vessels.

Would there be different requirements for small Autonomous/remote vessels as opposed to larger autonomous/remote control vessels?	To understand if industry experts see the need for different or separate requirements and rules for autonomous and remote shipping operations based on the vessel size.
Would any measures be required to separate remote/autonomous vessels from conventional manned vessels?	To understand if port authorities see the need for the separation or routing of autonomous and remote shipping operations from conventional vessels.
What additional safety measures if any would you propose for the operation of autonomous or remote-control vessels within port areas or approaches?	To understand what port authorities see as the additional requirements for remote shipping operations within their areas of responsibility.

4 Analysis of Results and Themes Derived from Interviews

4.1 Summary of Themes Extrapolated from Interviews

From the interview process carried out, the following table summarises the thirteen main themes which emerged from the responses provided by participants:

Table 3. Summary of Analysis

Main Theme from Interviews	Summary of Responses
New Services will be required	Dedicated private communication interfaces and networks will be essential to facilitate new operational services safely in port areas. Improved AIS and vessel monitoring system. Additional bi-directional shared information exchange between vessels and ports/VTS. Secure robust communications networks. Additional VTS stations and possibly remote pilot consoles.
Pilot Access	Concerns must be addressed for pilots to safely access vessels if there is no crew on board the ship. May be

	addressed by adaptations to provide for remote pilotage operations.
Legal Uncertainty	Concerns were raised as to who is responsible if there is an incident within a port area or while a vessel is under the directional advice from a pilot or port authority. Additional concerns were raised as to who is the defined ship Master if there is no crew on board and consequently, who has legal responsibility in the event of an accident? National and local port and harbour byelaws will require updating. This may be long legal process which may require government policy approval. Most current legislation is based on a human being present on board the vessel. This will entail many changes to a wide volume of existing legislation.
Communications	Concerns were raised in relation to communications having the available bandwidth necessary to handle data requirements. In addition, issues of resilience and coverage for communication systems were raised. Data latency was as concern, particularly where real-time instantaneous decisions and vessel reactions are required. This is a safety critical issue in ports and for ship operations in close quarters. Security of information, and the potential vulnerability of current networks to interference or malicious attack was raised. The requirement of communications standardisation and harmonisation between conventional and future autonomous or remotely controlled vessels was raised.
Human Factor	The points that emerged in relation to this theme included, concerns over the ability of autonomous or remotely controlled vessels to handle unforeseen circumstances or situations. Will a machine be capable of sharing accurate and useful information with relevant ports and ships in its vicinity? Can an autonomous or remotely controlled vessel interpret terms and definition, particularly those of COLREGs in the same way as humans? Lack of social cues and non-verbal communication

	associated with autonomous or remotely controlled vessels may present issues.
COLREGs	For autonomous or remotely controlled vessels, will mariners be involved in assessing compliance with COLREGs during software development phase?
Transition period risk	Port authorities see a need for safety zones and safety margin factors to be included throughout development and transition periods during the introduction of autonomous or remotely controlled vessels. Information campaigns must be put in place to educate all stake holders throughout any transitionary introduction period of autonomous or remotely controlled vessels.
Small vessels	There was general view that smaller autonomous or remotely controlled vessels may be considered as a stepping-stone to larger autonomous or remote operations. However, the requirements for small vessels should be in line with those of larger ships.
Separation	The view in relation to separation of autonomous or remotely controlled vessels from conventional ships was that this is already addressed by existing procedures.
Programming	Concerns were raised on the ability for autonomous or remotely controlled vessels to be programmed with complete and up-to-date local information, such as wind conditions and tides. There was view that mariners should be involved throughout software development so that vessel behaviour is reflective of human operation.
Additional safety measures	Adequate safety zones and information campaigns were raised as necessary additional safety measures. There were also recommendations that autonomous or remotely controlled vessels should be identified with unique lights and shapes.
Safely Interact	There was generally a positive view from participants in relation to the interaction of autonomous or remotely controlled vessels with conventional vessels.

4.2 Applied Analysis Method

The qualitative coding process was applied to form the basis of the analysis of this research. This method involved categorising interview quotes from the qualitative interview responses. This was done to identify the key themes which are considered important to harbour authorities. This also facilitated the structuring of participant replies from the semi-structured interviews into the identified themes for analysis.

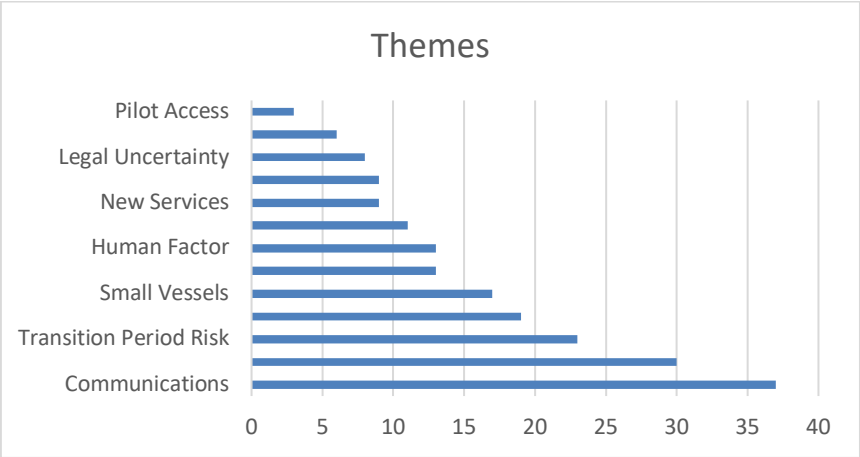
The participants' key interview statements were extracted as per the coding method. Each theme was then analysed to determine the strength of the individual themes obtained from the interviews. This also facilitated the identification of the most common views from the participants. The subject codes where then collated into the various themes which started to emerge as the analysis continued. From the analysis, some of the codes were applicable to more than one theme. In such instances, these codes were allocated to multiple themes.

An analysis of the interview transcripts was carried out to determine what themes emerged from the interview process. The interviews were based on the questions posed in section 3.4. At the conclusion of the analysis a total of 13 themes emerged from the data collected. The themes included 198 coded quotes which were assigned to the appropriate theme.

4.3 Analysis of Interview Responses

The seven main themes which emerged throughout the interviews are displayed in the chart below. This chart visually demonstrates the major themes which emerged from the collated interviews based on quotations derived from participants responses.

Table 4. Interview Main Themes Distribution Chart



To further analyse the insights and information offered by participants, the major themes derived from the interview process were subsequently scrutinised and examined individually. This analysis was carried out with the findings for each theme detailed for each topic below. Key insights from participants in the form of direct quotes are included and within quotation marks:

4.3.1 Pilot Access

Pilot access was the issue that emerged least among the themes and was raised by three interviewees. They all questioned the process of getting on board with one participant considering that in the early stage of MASS, they still may embark a pilot for the port entry portion of the voyage; “So it could be the first iteration might be that the autonomous vessel transits to a pilot boarding area, and then it embarks a pilot. So then you have issues with access for the pilot”

From an analysis of the interviews, access to the ships by the pilot was not raised as a common issue as it was considered that pilots would not be placed on the vessels if there was no crew there to interact with.

Where some participants initially considered the placement of a pilot on board a ship, it became apparent that the role of the pilot would not be best served by being there in person thus negating to need for pilot access to the ship.

The removal of a requirement for a pilot to board a vessel will reduce equipment required for safe boarding under regulation 23 of the SOLAS Convention thus reducing costs for the

operator and reducing risks to the safety of pilots in the often-dangerous task of transferring between a pilot vessel and a ship at sea.

4.3.2 COLREGs

The regulations for the prevention of collisions at sea (COLREGS) were raised by six participants. The general view of participants was that MASS vessels should follow the same rules as conventional vessels without any special privileges or obligations.

There were some concerns expressed surrounding programming and decision making in relation to vessels that may not follow a straight A to B track line.

“One of the issues speaking from my own side from a smaller Harbour, is that the users in the harbour, fishing and leisure, might not be as familiar with COLREGs as they should be. They may not react as required by the COLREGs, so I suppose, how will the unmanned manned vessel that's been programmed with an algorithm be able to cope with unexpected course and speed changes by fishing vessels and sailing vessels”

One participant was of the view that an autonomous vessel should give way to other vessels at all times: “I think probably the autonomous one would have to be the give way vessel at all stages”

The author did not include a specific question on the collision regulations so that participants would not be steered towards commenting on an area that the author considered problematic for the operation of these vessels in accordance with current regulations. The author had expected this to be an area of concern; however, it was not considered to be an impediment to operations in port areas by participants. It appears to be more of a concern that some operators of conventional operators may have a poor understanding of the rules and that an autonomous or remote vessel will have to allow for this, which is not a great departure from the current situation.

4.3.3 Legal Uncertainty

Four participants raised issues in relation to legal uncertainty surrounding MASS vessels both in relation to international conventions and local bylaws in harbours. One participant asked, “Who is the Master?” “Who is going to take legal conduct of the autonomous vessel,

if you have confusion in today's world with conventional vessels, this needs to be very very clear in its material understanding of who has responsibility for the autonomous vessel?"

The issue of the pilot's role and responsibility was raised: "what would be the pilot's role or responsibility be from a legal perspective really comes in because the pilot actually advises the master, he doesn't take command or control. So therefore, you're now, probably straying into a very grey area if you don't have a master on board the vessel?"

From an analysis of the interviews, legal uncertainty surrounding the identification of who has command of the vessel was not raised as a major impediment to MASS operation; however, it was something that some participants raised as requiring clarity. This issue will require clarity from national maritime administrations, the International Maritime Organization and the United Nations through the United Nations Convention on the Law of the Sea.

4.3.4 Programming

Programming was raised by six of the participants. A number of them were concerned that the more detailed data for port entry would have to be preprogramed in advance, such as the kind of specialized local knowledge that a pilot would have in relation to tides and currents that would not be available from databases as expressed in the participant quotes that follow;

"For instance, wind conditions and, and freshwater, that local experience is very hard to build an algorithm for at the moment, certainly without a lot of very detailed analysis of the harbour, it would be very difficult to quantify. And that was where one of our things with the use and track control or the experiments with track control with the cruise liners coming in. They couldn't anticipate the differing currents, you know, the fact that they go, you know that they're not linear, you know, even if they have vectors in certain places that they wouldn't apply enough helm or as they applied too much helm. And whereas you found with a human they put in a much gentler turn but much earlier, whereas with the track control, it leaves it much later. And you find it's a quite a different position and it might be slap right down the middle, but it tends to bring the vessel much wider, your margins are brought out to the limit much more. And I'm sure this can be engineered, but it will be a big thing with modelling and getting that right, you know, whether all the autonomous vessels can talk to this modelling."

“They need to be able to follow the same so they need to be able to follow COLREGs as a conventional vessel would. And obviously, with preprogramed algorithms that have been trailed and tested.”

“It's very important that autonomous vessels are integrated in properly with feedback from mariners, of course, not people who like design and stuff, you know, it's needs to be actual operational people.”

The analysis of the interviews showed that there were some concerns raised around the control of vessels by computers and what kind of algorithms were used to make decisions. These concerns can be broken into two areas. The first concern was that sufficient data will not be available for all ports to allow a computer to make decisions that a human with local knowledge can make and will not be able to anticipate situations and address them before they occur thus requiring less dramatic actions and movements.

The other concern raised in relation to programming was that the programmers may not include operational mariners in the development and design of control systems and may not be aware of requirements or limitations of the equipment. It is important to remember that human error may be a factor in software development and it must be correctly tested, including for exceptional circumstances and surprising situations (Ahvenjärvi, S., 2016).

The concerns surrounding the capturing of maritime knowledge in programming decisions highlight the need for mariners to be involved in the design of systems at an early stage. Another too to be considered is the use of simulators to assess how humans make decisions combined with analysis of data from ships in various locations and conditions to be used to train machine and build better machine learning tools. There may be a need to develop databases of port specific data to allow machines to prepare for port entry in particular for difficult ports with strong or complicated tidal effects.

4.3.5 New Services

Five of the participants expressed the view that ports would have to provide new infrastructure, technology, and services to be able to safely manage MASS vessels in particular in relation to sensors and communications equipment.

“You can have a lighthouse hosting equipment for line-of-sight communication, stuff like that. we have to have the right information at the right point of time.”

“If you go down that road of VTS, well, then it's one on one with that ship, the VTS is taken away, so you need more manning levels in the VTS because your VTS officer will be focused on that specific ship.”

“Certainly, if you're piloting them remotely, you'd need a much higher degree of independent sensors. Whereas at the moment, we can get away with fewer sensors, because we still have eyeballs, we still have a pilot or a PEC, and you need to increase the reliability”

“Things like, base stations at the moment, we, you know, to back up our VTS, we actually use pretty standard AIS receivers, but you'd be looking at base stations. So you can increase the refresh rates and things like that. We can't do that at the moment. And you know, it certainly makes them a nice tool to help but it's very, very much on the lower end of being an aid. You know, really the only thing you nearly rely on, it's actually where they are not what they're doing, because the latency is there. So you need to reduce latency, increase the refresh rates and increase the number of sensors.

“You be would you be running towards ports having your own 5G networks where perhaps these vessels as they transit into the port, switch over into the port network and becomes an entirely secure closed loop network, then from the point of view of transfer of data or messages? This was more of a question really, you can probably set up communication protocols and channels between a well-established port authority or VTS, and an autonomous ship. But can you set up communication protocols between the autonomous ship and other manned vessels? How are you going to cope with that?”

The analysis of interviews indicated concerns around the provision of data for MASS vessels and that additional services and resources will be required by ports to facilitate their operation. It was felt that there would need to be a substantial increase in the amount of data provided on actions and movements within a port so that an autonomous or remotely controlled ship could be armed with the level of information that a human on board will have just by observing their surrounding and other ships in the port. This information is generally supplemented with voice information from other port users, pilots, tugs, and vessel traffic services. This information often includes advice by voice on tides in different areas or traffic movements that can be expected.

There will be a need for all this supplemental information that is available to assist ships to safely move within a port to be made available in data formats that machines can interpret

including planned operations in the port. This information will also have to be secure and available throughout the port and at sufficient data speeds for decision making.

4.3.6 Safely Interact

Most of the participants were of the view that MASS vessels could safety interact with conventional vessels.

“I do. And they’d have to be identified, By day and by night. I also believe that by proper promulgation and proper education, like I mean, if I were to do that here, I would have endless consultation phases with the same with the sailors, with the fishermen, with the bay users, even the jet ski operators and drill it into them that these vessels are operating and there is nobody on board and with good comms you can, as seafarers are great at achieving the impossible. And then yes, absolutely that autonomous ships can operate with manned or traditional manned ships.”

“Yeah, like, I actually don't see a big problem with that to tell you the truth. I think like anything new that you're going to introduce into any port, right, or any business, you know, you're going to have a testbed for a period of time, you're going to have maybe designated areas where these craft could operate for a period of time or designated area, where the manned smaller craft or leisure craft don't operate. But a segregation certainly, I think as individuals and river users, both commercial and leisure, get used to autonomous ships, just like they get used to any other platform that's in the port or a special operation that's going on, there's an awareness there and training that's rolled out. So I do think that they can work well enough together. I mean, we are like, if you look at the automotive industry, they are advancing rapidly towards automation, and you know, in trucking and in vehicles, and they've had several test beds going. So I actually don't see that as a particularly huge problem. I think that's a very manageable problem”

Only one participant was of the view that the interaction of conventional and autonomous or remote-control vessels couldn’t happen safely. One participant had hesitation around fully autonomous vessels operating safely in a mixed traffic environment. One participant expressed a lack of confidence in mixed traffic at this time, and at the current stage of technology development.

According to the analysis there was a general view there would be no difficulty in the safe interaction of MASS and conventional vessels in port areas. It was considered by

participants as a regular part of port approaches to have to deal with mixed and irregular traffic. Ports are used to handling differing types and vessels and floating objects in their jurisdiction. Ports will equally be able to safely introduce mixed unmanned and conventional traffic through control of the space as required and ensuring that all traffic in the port is aware of any unusual vessels or traffic movements.

4.3.7 Human Factor

Seven participants raised human factor issues in their interviews. This was raised as different issues in relation to port approaches and pilotage. Some of the comments related to machines or remote operators not having the benefit of local knowledge of rivers, tides and currents which may not be available in published maritime information. Other participants' views concerned the application of rules by a machine in comparison to human decisions where flexibility or interpretation may be required.

The other issue raised was in relation to the kind of confirmation that pilots get when giving advice that it has been understood; this may be by facial expressions, response, body language or general demeanour. There was a concern that when communicating with a vessel control centre that you lose this non-verbal communication. There was also concern that you have less information about the ship without the noises that give you a feel for what is happening.

"Things like the pre arrival checklist and the master pilot exchange, they're going to become more important than ever, you might think, well, why are they more important because they're not face to face, you're going to have to do this well in advance. You're also missing that the pilots going to miss that human interaction, that vibe that they get, that sense that they get of how things are when they walk on the bridge, so they are going to be missing this"

"I suppose the thing is not so much the remote vessel or the autonomous vessel being the issue, it's probably the manned vessels, and the way they interpret the regulations, like if everything's on the playing off the same, the same sort of set of rules, and I know in theory, you all are, but the human factor is still a big element and you know, while everybody should stick to the same rules, there is always that last minute problem, you know, and the human factor comes in. So that will be the challenge there in marrying the pair"

“How does the Port Authority advise, perhaps the next autonomous vessel is coming in behind them going in front of you has spotted something you know, so it's, it's trying to figure out where it lies with that very important kind of human factor that can feed back in a very dynamic situation, how we can get that information back that we might need to pass on pretty quickly to somebody else”

“Exchanging information, and you're clarifying that what you've said is understood and vice versa, looking at somebody in the eye for me, it sort of, you know, call it the human element. And, you know, by looking at somebody whether they understand you or don't if I suppose if I was talking to a guy and a headset or headphones, and I don't know why there need to be looking at him, and we're both controlling the same ship”

“You're also missing that the pilots going to miss that human interaction, that vibe that they get, that sense that they get of how things are when they walk on the bridge”

Based on the interview analysis there were a number of areas where the human factor was a concern. Among the areas of concern were what happens when things go wrong, and will an autonomous vessel be able to handle an unusual situation or incident that may require some consideration or that it may not have seen before. Connected to this was whether the vessel could advise the port of other vessels in the area if it had a problem or something as simple as a wish to slow down or alter course in an area where its movements may affect others.

Concerns were raised by some participants around a MASS vessel being able to interpret terms that human navigators are used to when applying the collision regulations, such a making a bold alteration or a large alteration.

There were also concerns that when a pilot is not on board and may be communicating from a vessel traffic centre with a vessel operator who may be located in vessel control centre, that there may be misunderstandings and delays. The social cues and non-verbal communication that a pilot may notice and quickly realize that what they have said was not understood or that there is a problem that they have not been made aware of will be missed. Time may be lost in becoming aware that there is a problem and thus reducing the time available to react to prevent an incident occurring.

4.3.8 Additional Safety Measures

Eight of the participants made comments on the requirement for additional safety measures that they may require for MASS vessels to operate in their port areas. Some of the recommendations were for earlier stages of MASS operations in order for ports to build trust that the operations could successfully take part in conjunction with conventional maritime traffic in a shared environment without any decrease in safety.

Some of the methods involved requiring greater safety distances between vessels and having an escort vessel or response vessel such as a tug available and on standby. Six of the participants were of the view that this would be required. Two of the participants gave the view that the ability to anchor in the event of a problem was required. Some of the measures proposed were more long term such as a specific shape or signal to be displayed to provide a visual identifier for other vessels in the area that it is a MASS vessel. Another view to emerge was the need to provide information on the existence of MASS operations to other port users and the wider marine leisure user.

“Slower speed of approach, larger safety zones maybe daylight docking and sailing, possibly guard ship escort vessel and those things can be relaxed in time and possibly larger safety distances between other vessels other manned ships”

“More stringent control measures, doing, first of all, maybe look at daily operations only certain weather conditions more restrictive, perhaps, definitely in the initial trial stages, before we actually roll it out properly”

“A prescribed visual, day or night identifier, should be assigned to these vessels, either a hull colour and a certain type of light at night, so people interacting with them are aware”

“May have to display certain lights or shapes or something, so you know, that's maybe something then you go back to the IMO, any autonomous vessel must display this symbol, day and night, so other users know”

“Do you need on do you need tugs on 24-hour standby if you're going to have an autonomous ship coming in, ready to go at any stage, because you're not going to have a crew on board to take the appropriate action as you know. Can the port trigger an action that an anchor can be dropped in an autonomous ship, so the range of protocols as we move up, and we get into

the finer details of how to actually control and manage the vessel in a congested port area, really, there's a lot of unanswered questions."

An analysis of the interviews found that a number of participants expressed a need for additional safety measures, most of these were for the early stages of operations and were seen as measures to take while building trust and confidence in MASS operations rather than any concern surrounding the concept of unmanned operations.

Most of the additional measures were proposals for information campaigns and warnings to other traffic and for greater safety zones around MASS vessels during the early stages of operations. There was a desire of participants' that in the early stages of operations that there would be a requirement for greater distances between MASS and other vessels. In the longer term it was stated that there was a requirement for measures to identify MASS such as a specific light at night and shape during the day. This is a measure that would have to be agreed on internationally at the International Maritime Organization so that there would not be confusion for ships which trade internationally and may not be aware of local signals used. It is important that a signal cannot be confused with a signal authorized by the COLREGs.

4.3.9 Small Vessels

The general view in relation to differing regulations for small vessels such as small remote survey vessels was that there could be fewer requirements for these vessels as they posed less risk to other vessels. They were seen as a starting point by some where the small vessels would operate first and build trust and prove the technology before bigger ones start to operate. Eight of the participants were of the view that there could be less stringent rules around the operation of small MASS vessels.

"I think there's less risk definitely with smaller autonomous vessels, so there can be a bit of leeway given"

"I think it will be different requirements for the big one and the small one, due to also the risk of what can happen"

“I suppose it'd be it'd be easier if you're talking about small, you know, there wouldn't be much of a risk there if it's only a four or 5 metre little thing. Obviously, the risk of that happening is far less than that a tanker or container ship”

“I suppose if you scale it from small vessels working up to big vessels, then you know, there'll be a certain amount of experience, and then that should work better at that point”

“We'll start with the smallest of the vessels, and then moving up to full size”

Based on an analysis of the interviews, there was not a view that differing rules may be required. However, a number of participants were of the view that due to the lesser risk associated with small vessels the rules surrounding their operation would not have to be as stringent and they could more readily commence operating. Small vessels were also seen as a stepping-stone to acceptance and a way to build confidence in the safety of the technology.

The potential risk of allowing less stringent regulatory requirements on small vessels may place additional burdens on the operators innovating and taking the first step to get it right. Failures in early operations have the potential to undermine confidence in the ability of MASS vessels to operate safely. Failures or accidents during operations by early innovators could cause considerable damage to the reputation of the industry and hinder its acceptance and development.

4.3.10 Separation

Ten of the participants gave views on the need for separation in various ways. Separation of traffic was seen by some participants as just a continuation of what is already done in ports with slot time or the order of ship entry. To a certain extent it was seen as just another vessel in a controlled slot and not really a new departure in port areas. Some were of the view that there was a need for a dedicated channel for MASS vessels however in narrow ports this was not necessarily possible.

“I think you would have to completely overhaul the slot times and the passing areas they would have to build a lot more flexibility into that and then allowing for the differing conditions”

“In the same way ferries get a slot time and a dedicated, I think to begin with I think it would be dedicated It’s autonomous hour, they’d get them all in”

“Ultimately I think they would need a dedicated channel, up to the berth”

“We probably won't have the room to separate out remote from autonomous vessels. And it's back to if the computer programs and algorithms are programmed correctly, the unmanned ships should obey the COLREGs the same as their manned counterpart. So therefore, there should be no need to separate them when they're when they're interacting in the water”

“I would prefer that it was possible to have the autonomous vessels sailing in like a time slot. So, you need, you know that there is available time for that vessel without any traffic. But that's because it's quite new, maybe in 10 years, maybe there can be more traffic, but I think it's important to start with that they can have a time slot without going and have all the fairways for themselves”

“we separate vessels anyway, as part of our traffic management, so, yes, they would, and I think I certainly in the early days to bring it to more established routine, yeah, I can see that there would be an increased safety factor built into it. But if you're starting very small vessels, you know, you should be able to route them on the more periphery parts of the channel, and you probably have more scope, then. So it really depends on what vessel is being autonomous. But at the beginning, absolutely, you'd have to separate.”

“I think maybe for a regular ferry, that would be a good idea to have a fairway that that only the autonomous vessel could use”

Based on an analysis of the interviews it was established that a number of the participants were of the view that separation may be required. In general the view was that separation could only be done by time slot. To enable this traffic separation may require the creation of areas where contraflow traffic would not be permitted. The avoidance of passing in these areas would be controlled by timed passing and controlled speed if required.

There was very little support for the creation of separate dedicated MASS traffic lanes as in general it was the view that most ports did not have the luxury of the available space and channel width required to enable this. The separation by time slot was not considered to be

a departure from current practice by most commercial ports as it is already routine for traffic management of conventional vessels.

4.3.11 Transition Period Risk

The potential of additional risk during the transition to MASS operations was an area where twelve of the participants raised concerns. There were some views that levels of separation were required initially in order to demonstrate the safety of the new technology. Seven of the study participants favoured some initial restrictions such as open waters, escort vessels, speed or area restrictions, clear navigation channel for the operation or indeed a stepped approach with crew on board initially. It was also considered important to communicate with other marine users that these vessel operations were taking place. Four of the participants stressed the provision of information to other mariners to be key to safe trials.

“I would have thought nothing else moves except the autonomous vessels until it’s all kind of ironed out and trailed out a few times”

“Slower speed of approach, larger safety zones maybe daylight docking and sailing, possibly guard ship escort vessel and those things can be relaxed in time and possibly larger safety distances between other vessels other manned ships”

“We probably have to do something like educational campaign or marine notice, I should say. And I suppose you would have to have a vessel shadowing the autonomous vessel, make sure that the vessel is responding to all communications”

“So you need, you know that there is available time for that vessel without any traffic. But that's because it's quite new, maybe in 10 years, maybe there can be more traffic, but I think it's important to start with that they can have a time slot without going and have all the fairways for themselves”

“I think I certainly in the early days to bring it to more established routine, yeah, I can see that there would be an increased safety factor built into it. But if you're starting very small vessels, you know, you should be able to route them on the more periphery parts of the channel, and you probably have more scope”

“You can see if you can cordon off an area, send your notice to mariners and say for the next three days, we are going to have an autonomous vessel of a certain size operating in this

area. And then you start to build confidence in the system, I think, as I said at the outset, we are probably quite a bit away from the commercial ship autonomous within piloted areas. And even when that comes, it'll probably be certain pilotage areas only, obviously, more simple ones first, an area like this where it's complex, a lot of dynamics going on, might be further down the line"

"I would have endless consultation phases with the (leisure) sailors, with the fishermen, with the bay users, even the jet ski operators and drill it into them that these vessels are operating and there is nobody on board"

Based on an analysis of the interview transcripts, there is not a feeling that there is a risk during the transition phase to the introduction of MASS vessels operating in the same areas as conventional vessels. The study displayed the need for an element of caution and a requirement to build up trust in the systems during the introduction of MASS operations.

Initially, ports may require wider safety margins such as the creation of safety zones around MASS vessels. During the initial stages of MASS operations ports may also require clear approach channels be available for a MASS vessel to enter or leave a port. It is likely that in the early stages of operations ports may have escort vessels or tugs accompanying MASS vessels on their port approach or departure so that they can intervene if required or warn other vessels that may encroach on a safety zone.

Information campaigns and wide promulgation of information concerning movements of MASS vessels to marine users in the area are considered essential to a smooth transition to mixed conventional and unmanned vessels. Additionally, ports are not yet ready to offer remote pilotage services to unmanned vessels and investments in new technology will be required to integrate these services into a port operation. At first there may not be uniform solutions for all vessels, there may have to be interim tailored solutions for individual operators in how they will communicate with a port with considerable liaison in advance of any operation and a continued relationship improving the process.

4.3.12 Remote Pilotage

Twelve of the participants made comments on remote pilotage. There was a general view that vessels would initially require a pilot on board to enter pilotage areas and as technology is proven it would be acceptable to remove to shore pilotage as the next stage. It was also

the view of some that for larger vessels, port legislation or local bye-laws would have to be amended.

“I would virtually be on the bridge doing all the stuff that the normal pilot would do during a normal pilotage operation, dealing with the tugs, requesting manoeuvres from them and obviously being mindful of the other traffic and VTS.”

“I see it as sort of different versions. So, it could be the first iteration might be that the autonomous vessel transits to a pilot boarding area, and then it embarks a pilot. So, then you have issues with access for the pilot and have issues which remotely authorizing access for the pilot, you may have a riding crew traveling out with the pilot to get on board to tie up the vessel. And next stage, I suppose if fully automated you could the pilot could actually conduct go to say the harbour ops building the VTS centre. And he could be in communications with the remote-control centre that's controlling the autonomous vessel. Or you could go the next level again, you could see the pilot actually goes into the remote-control centre. And then you have you could have full, like proper integration with the whole bridge team who are driving the ship remotely”

“At the moment, I wouldn't have thought the remote systems were in place so we still have to see a technology that would allow a remote pilotage situation”

“I think in the initial stage the policy we might put in place is that every autonomous ship would come to a point, and would be escorted, would be manned into the harbour. So, so I suppose therein would lie the issue with the pilot. Should they need to intervene, they would need to know how to intervene and every vessel being different, that their lies the issue of, you know, exposure to those types of controls and systems on board.”

“You're really looking at an entirely different skill set for the pilot as well, an entirely different awareness level for the pilot. So, I see that as a major challenge”

From an analysis of the interviews, it was clear that once you discuss remote pilotage, participants tend to consider larger vessels in their analysis. This outlook on vessels subject to pilotage arises as most ports in Ireland only require a pilot on larger vessels. Where discussions on ships subject to the requirement to carry a pilot arise, the size ships being considered are generally ships over 70 metres depending on the individual port. For ports the prospect of larger MASS vessels operating becomes riskier. This is especially the case in ports with narrow rivers, bends and strong tides, where navigation is more complicated.

For vessels subject to pilotage, it is unlikely that ports in Ireland would allow them to operate uncrewed. Initially, ports would expect a pilot and crew on board to prove that the ship is capable of entering and leaving the port without intervention. The ship would need to be able to demonstrate that it has the capability to deal with wind and tide effects with accuracy and predictability. The ship would have to demonstrate that it can take appropriate levels of action with propulsion and steering to ensure manoeuvring movements are smooth and timely. Inaccurate predictions could lead to overcorrecting, using large alterations of course and speed which may bring vessel into danger. Erratic or unpredictable manoeuvres could also endanger other vessels or property in the port.

One of the concerns that participants have is the ability of technology to transfer large amounts of real time data for decision making without any latency between the ship and port. Communications technology for MASS operations must also ensure coverage of all areas of the port without black spots or dead zones. The communications infrastructure also needs to be resilient and secure. From a responsibility and legal perspective ports will require that operating a vessel without a Master on board is provided for in domestic legislation.

4.3.13 Communications

Twelve of the participants commented on communications issues for MASS operations. The main issues of concern were bandwidth for the greater volumes of data transfer, resilience of communications, latency in communications, security of communications and compatibility of communications equipment between ports, MASS vessels and conventional vessels.

“I imagine it’s this sort of drone scenario where you go into a dedicated space, you’re completely separated from everybody else and you’ve got your screen and your VHF and your AIS, all of that information. I would have thought that you’re interreacting with some human element in not on the ship, remotely or whatever and the pair of you work together to berth the vessel.”

“It should be the same level of communications if not even more advanced, so primarily by VHF between the remote-control center and the tugs and the pilot. So instead of talking to the bridge, you're talking to the remote-control center who are who are driving.”

And the ships, they need to be GMDSS compatible, they need to be radar with automatic radar tracking, AIS, your on board sensors are going to become very, very important your visual, your audio for relaying sounds around the vessel, all that sense of stuff that you get when you're on the bridge, that you can walk out on the bridge wing and get another thing that's going to be very important"

"I see communications being much the same, of course they're going to require a much heavier bandwidth and you will see alternatives come and I think ports can provide the infrastructure for these communications"

"We can't have some guy in the middle of the river computer controlled and next thing we have blackout, we got power failure, he can't get signal, IT is gone down, there has been corruption, all these things causing a whole bag of hassle, that just can't happen"

"Can you imagine coming in through breakwaters and suddenly there is a communication failure"

"I think from a risk management point of view, it would have to be over an encrypted channel with redundancy. You'd need at least 100% redundancy, so two channels to the vessel. The reason it would need to be encrypted is so that conflicting instructions can't be provided by rogue person that has a VHF radio, so you need something secure.

"The only trouble with VHF is that it is possible for somebody to over transmit on the current Marine VHF channel, you probably would be looking at a closed system."

"You need to reduce latency, increase the refresh rates and increase the number of sensors"

"The transfer of data or any type of communication between the vessel and whatever shore station or individual is interacting, the security of that is going to be highly important"

"Ports having your own 5G networks where perhaps these vessels as they transit into the port, switch over into the port network and becomes an entirely secure closed loop network, then from the point of view of transfer of data or messages? This was more of a question then with that is really, you can probably set up communication protocols and channels between a well-established port authority or VTS, and an autonomous ship. But can you set up communication protocols between the autonomous ship and other manned vessels"

Based on an analysis of the interviews conducted, communications were raised as the greatest concern that participants had with the introduction of MASS vessels. There were a number of issues that concerned participants and would have to be addressed before they would be satisfied that MASS operations could take place within their ports.

An issue of concern was bandwidth for the greater volumes of data transfer between ships/ports and the ship control centre; often the approaches to ports are in isolated areas with limited cellular coverage and operations may be reliant on satellite communications during the more complicated part of a voyage where large volumes of data will be required to safety oversee the vessel approach. The port may require CCTV, Radar, Automatic Identification Systems, Very High Frequency (VHF) radio. The port may also require oversight of ship systems such as engine monitoring, steering and auxiliary systems for MASS vessels.

Resilience will be required in the communications systems used. Concerns were expressed by participants hat a vessel could have a black out at a critical stage such as when in the middle of a river. They could be in this location without any power and no human on board to intervene and rectify the situation. Additionally, there would be no person on board to prepare emergency measures such as deploying an anchor to ensure that the vessel is not presenting a danger to the safety of navigation or the marine environment.

Participants were also concerned about latency in communications where the data is not refreshed quickly enough and instant decisions and actions are required such as when berthing where the ship may have to deal with a sudden gust of wind or unusual tide effect around a berth.

Secure communications were considered important by participants to ensure that the correct information is going to the correct ships. It was considered vital by participants that ships cannot receive information from malicious or unreliable sources whether accidental or intentional. Some ports noted that they had already invested heavily in private networks within their terminals to ensure secure and reliable communications, within their control and not reliant on third party providers.

Standardization and compatibility of communications equipment between ports, MASS vessels and conventional vessels were considered key to operations being successful. If ports are being expected to invest large sums of money in new communications infrastructure,

they need to be certain that it will be compatible with all ships calling to the ports and interoperable with all conventional ship's existing systems for ship-to-ship communications.

5 Discussion and Critical Review

The aim of this study was to look at the area of remote control and autonomous vessel operations in port areas and approaches. For the purposes of the study these vessels were assumed to be uncrewed. Existing research has mostly looked at the control and operation of these vessels. However, very limited existing research has investigated the port approach and pilotage area part of a voyage which takes place within the jurisdiction of individual ports with unique attributes, conditions and local regulations.

This study looked at operations in the context of ports in Ireland where there is no national vessel traffic service and only one port in the country has a port vessel traffic service. The interviewees selected to take part in the study were drawn from a wide selection of ports in Ireland covering large commercial ports, fisheries harbours and the largest leisure harbours in Ireland. It also included local authority-controlled areas which have responsibility for a variety of facilities from commercial ports, fishing harbours, leisure harbours right down to small piers and slip ways.

A wide geographical spread of interviewees was selected covering the country and different levels of traffic density and coast types from more sheltered coasts to the more exposed Atlantic region.

The interviewees selected were a mixture of Harbour Masters, Port Marine Officers, Pilots and VTS operators. One VTS operator was selected from outside Ireland to get some context from a national VTS service perspective. All the interviewees were qualified navigators, and most have had command of ships.

The overarching question of the study was to determine from the ports' perspective how remote controlled and autonomous vessels could operate in port areas and to examine what difficulties there may be and what safety measures would be required by ports in order to allow these operations to take place safely to the satisfaction of ports.

The author had expected there to be considerable commentary on the regulations for the prevention of collisions at Sea (the rule of the road for ships); however, that was not to the forefront of the concerns of the port sector community interviewed.

In general, there was a feeling that the operation of remote-control and autonomous vessels was possible however there was an element of trust required to be developed with the port sector to gain acceptance of the safety of these operations. To develop this trust, it may require additional measures in place in the early stages such as escort vessels. Others measures during early-stage operations may involve starting with smaller vessels until they can demonstrate an equivalent level of safety in comparison to conventional manned vessels.

There was a view that smaller vessels posed less risk to other marine users and had the ability to keep clear of main shipping channels in larger ports to avoid conflict with other traffic. Also suggested was the use of larger safety zones around these vessels initially so that there is a greater distance kept between vessels.

It was considered very important in the initial stages of the operation to have substantial consultation and information campaigns with other marine users including the fishing and leisure sectors to ensure that they have an awareness of this type of vessel and an understanding that there is no one on board. It was also considered necessary to use formal notices to mariners or warnings to marine users that these operations were taking place.

The area of most concern to the participants of this study was in relation to communications between the ports, pilots, conventional vessels and remote-control/autonomous vessels. This concern was wide ranging and covered bandwidth availability for large data transfers. Another concern was how to deal with latency in communications where urgent decisions had to be made and real time data was required in addition to act immediately on this information.

Compatibility of communications was a concern as there would have to be agreed formats and protocols to communicate with existing equipment on conventional vessels and with ports. It was also considered essential that these communications were secure so that there would not be misunderstandings or malicious interference in communications. Some expressed the view that ports may need to upgrade equipment to ensure security and resilience of communication withing the port area. It was also the view that additional sensing and monitoring equipment would be required in port areas to ensure that a real time

situational awareness or port traffic was maintained and that this was resilient and not at risk of a single point of failure.

There was some support for separation of remote-control/autonomous vessels from conventional traffic however, in general participants formed the view that this was not practicable due to space and depth constraints in port areas. There was considerable support for separation by time such as using allocated slot times; this was not considered a departure from current practices in port traffic management. The use of time slots was seen as routine and a pragmatic way to ensure safe operations.

The need for lights and shapes to identify remote-controlled and autonomous vessels was considered to be a useful addition for other marine users. In pilotage areas the loss of the human factor was a concern where there may not be a harbour pilot on the vessel. This was expressed mainly as two differing concerns. The first was when a pilot is conducting remote pilotage; there were concerns that you would potentially have a misunderstanding by being unable to see the expressions and social cues of the vessel operator. Because of this the pilot may miss the opportunity to observe when instructions have not been understood. The pilot may miss that sense that there is a problem on the bridge of a ship.

The second aspect of the human factor that caused concern was on vessels with no pilot in the loop, in particular in relation to autonomous vessels. There were concerns around the lack of local knowledge in areas such as tide effects and localized currents; the view of participants was that this information is not available in any database. This information would not be able to be included in the programming of a vessel. This information gap could result in reactive decisions by vessels to external forces which may cause erratic manoeuvres by vessels. The lack of local information could cause autonomous vessels to overcompensate for unexpected conditions. This may require increased safety margins to be allowed for in ship route planning.

In general, there was a view that these operations could safely take place, The view of participants was that there was need for legal certainty surrounding responsibility and to clarify who has legal command of a vessel. There was also the view that considerable investment would be required by ports in sensor and communications equipment and that international standards and protocols for communications were required.

From the analysis of these interviews the author has determined steps that should be taken to safely develop the operation of remote-control and autonomous operations. At an international level, there should be consideration on the need for special lights and shapes to be displayed by these vessels to identify them to other vessels and marine users.

Communication methods, protocols and standardization are urgently required to ensure these vessels can communicate with ports, pilots and conventional vessels to ensure that operation scan be conducted safely and securely.

Based on this work, further information has been obtained from relevant maritime experts with specific expertise in Irish ports. The views of these experts have been collated and analysed and a further understanding of the specific questions set out in the research aims has been developed.

The following questions related pilotage operations within Irish ports and harbours have been comprehensively addressed with the views of relevant experts:

- Is the operation of autonomous or remote-control vessels within port areas or approaches under discussion within relevant organisations?
- What are the expert views on how pilotage could be conducted on remote controlled or autonomous vessels?
- How do experts see communications taking place between autonomous or remote vessels in relation to instructions from the port authorities and communications with pilots, tugs and other vessels?
- Do experts think that remote/autonomous vessels can safely interact with other traffic in port areas?
- Is there a need in the view of experts for different requirements for smaller autonomous/remote vessels as opposed to larger autonomous/remote control vessels?
- Do experts see a need for measures to separate remote/autonomous vessels from conventional manned vessels?
- What additional safety measures, if any, would experts propose for the operation of autonomous or remote-control vessels within port areas or approaches?

Through the methodology applied and analysis carried out, this research work may provide a contribution to the necessary operational and legislative developments which will be required to facilitate autonomous and remote operations within Irish ports and VTS areas.

6 Conclusion

It is apparent that significant operational and legal challenges remain a barrier to the operation of autonomous and remotely controlled vessels within Irish ports. It is clear from the views of relevant maritime and port decision makers that such vessels will require a heightened level of monitoring. Experts have also recognized that there is a need for such vessels to interact and communicate seamlessly with conventional ships, other maritime users, port facilities and VTS shore-side facilities.

These crucial obligations will require extensive legislative change at national level to facilitate these operations. In addition, communications infrastructure and systems will need to be put in place to address legitimate concerns of port authorities. It is likely that international regulations and standards will need to be developed to facilitate the harmonization and standardisation of global communications equipment and procedures.

The responses and analysis of the research interviews carried out has provided a novel insight from national experts and port authorities. The views collated within this work are important as these contributions highlight the concerns of key industry decision makers. It is crucial that these concerns are adequately addressed so that port authorities can have confidence and will be accepting of autonomous or remote vessel operations within their areas of responsibility.

This work has contributed to the understanding of autonomous and remote vessel operations, by primarily identifying real world port and pilotage issues. Many of the challenges identified may be overcome with the development of new technologies. However, acceptance of port authorities is essential. In order to advance the regulatory changes necessary to facilitate autonomous and remote vessel operations within Ireland, it is vital that the issues raised within this work be addressed through further research and development within this exciting and emerging maritime sector.

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