Impact of maritime autonomous surface ships (MASS) on VTS operations

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WORLD MARITIME UNIVERSITY
Malmö, Sweden

Impact of Maritime Autonomous Surface Ships (MASS) on VTS Operations

By
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Republic of Singapore

A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the degree of
MASTER OF SCIENCE
In
MARITIME AFFAIRS
(MARITIME SAFETY AND ENVIRONMENT ADMINISTRATION)

2018

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): ...........................................

(Date): September 18, 2018

Supervised by: Michael Baldauf

Supervisor’s affiliation: Maritime Safety and Environment Administration
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“Knowledge is true opinion.” - Plato

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ABSTRACT

Title of Dissertation: The Impact of Maritime Autonomous Surface Ships (MASS) on VTS Operations.
Degree: Master of Science

VTS operations relies on human to human interaction to deliver its services for safety of navigation. This tradition was established more than six decades ago. Today, many of the VTS operating procedures are developed based on this relationship with Master and crew.

However, this relationship is about to change by the introduction of Maritime Autonomous Surface Ship (MASS). This new emerging technology is drawing the interest of the maritime industry towards its ambitious technological developments in automation. Research on advanced automation points to a number of reasons for augmenting or replacing humans in the operational loop, including issues related to safety, human error, cost-effective shipping, advancing technologies in shipbuilding, and overall environmental compliance. Although commercial unmanned shipping does not yet exist, it is worth considering the influence of this emerging technology on VTS operations.

This dissertation researches the potential impact of MASS on VTS operations. The researcher uses Gap Analysis to assess the difference between current VTS operations and the future. To identify the potential gaps, results attained in the scientific analysis of SWOT-AHP from the Istanbul Technical University was used as a guide. Observations and experiences drawn from the participation of simulation study was evaluated. Potential gaps were discussed and analysed against International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) recommendations and guidelines. It is hoped that the result of this study might help VTS Authorities understand the potential impact of MASS on VTS operations.

Keywords: Vessel traffic services (VTS), Unmanned ship, Autonomous ship, Shore control centre (SCC), Maritime Autonomous Surface Ships (MASS)
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LIST OF ABBREVIATIONS

AAWA  Advanced Autonomous Waterborne Applications
ACTUV  Anti-Submarine Warfare Continuous Trail Unmanned Vessel
AHP  Analytic Hierarchy Process
AIS  Automatic Identification System
AL  Autonomy Levels
ARPA  Automatic Radar Plotting Aid
AtoN  Aids to Navigation
CCTV  Close-Circuit Television
CONOPs  Concept of Operations
COLREGs  Convention on the International Regulations for Preventing Collisions at Sea, 1972
DNV GL  Det Norske Veritas and Germanischer Lloyd
DOS  Denial of Service
EC  European Commission
ECDIS  Electronic Chart Display and Information System
ECT  Emergency Control Team
ETA  Estimated Time of Arrival
EU  European Union
IALA  International Association of Marine Aids to Navigation and Lighthouse Authorities
GNSS  Global Navigation Satellite System
GPS  Global Positioning System
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ICT</td>
<td>Information and Communications Technology</td>
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<td>IMO</td>
<td>International Maritime Organization</td>
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<td>INS</td>
<td>Information Service</td>
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<td>ITU</td>
<td>Istanbul Technical University</td>
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<td>LR</td>
<td>Lloyd's Register</td>
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<td>MASS</td>
<td>Maritime Autonomous Surface Ships</td>
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<td>MSC</td>
<td>Maritime Safety Committee</td>
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<td>MUNIN</td>
<td>Maritime Unmanned Navigation through Intelligence in Networks</td>
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<tr>
<td>NAS</td>
<td>Navigational Assistance Service</td>
</tr>
<tr>
<td>NTNU</td>
<td>Norwegian University of Science and Technology</td>
</tr>
<tr>
<td>NUC</td>
<td>Not-Under-Command</td>
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<tr>
<td>OCT</td>
<td>On-board Control Team</td>
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<td>SA</td>
<td>Situational Awareness</td>
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<td>SAR</td>
<td>Search and Rescue</td>
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<td>SCC</td>
<td>Shore Control Centre</td>
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<tr>
<td>SOLAS</td>
<td>International Convention for the Safety of Life at Sea</td>
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<tr>
<td>STCW</td>
<td>International Convention on Standards of Training, Certification and Watchkeeping for Seafarers</td>
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<tr>
<td>TOS</td>
<td>Traffic Organisation Service</td>
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<tr>
<td>TSS</td>
<td>Traffic Separation Schemes</td>
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<tr>
<td>VHF</td>
<td>Very High Frequency</td>
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<tr>
<td>VTIS</td>
<td>Vessel Traffic Information Services</td>
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</table>
VTS    Vessel Traffic Services
VTSO   Vessel Traffic Services Operators
WMU    World Maritime University
1 INTRODUCTION

1.1 Shipping and VTS

Maritime nations have long recognised the need to enhance the safety of navigation to facilitate safe seaborne trade. Seeing the need to attract more shipping activities to improve trade and economy, coastal States were compelled to provide better infrastructure and navigation assistance services from ashore.

Aids to Navigation (AtoN) were introduced more than hundreds of years ago to assist vessels to navigate safely in and around coastal waters, and approaches to and from ports. Visual aids such as lighthouses, beacons and buoys were used to mark the safe limits of fairways, natural and other obstructions, isolated shoals, wrecks, and new dangers. With growing shipping traffic, more AtoNs were established and further developed to help mariners with safe navigation.

The continued growth of shipping traffic demands more effective management of shipping in coastal waters. Routeing measures such as Traffic Separation Schemes (TSS), Precautionary Areas, Inshore Traffic Zones and Deep Water Routes were introduced. These routeing measures are used to organise traffic movements in an orderly manner. This minimised ship-to-ship interaction and increased the safety of navigation, thereby reducing the risk of collision. This is similar to road traffic where vehicles are assigned to drive in dedicated lanes.

The effectiveness of AtoNs and Routeing Measures were limited. Close monitoring of traffic is required to mitigate the increasing risks caused by more traffic, growing ship dimensions, emerging risks in the maritime domain, dangerous goods movements, security threats, and the need to protect the marine environment.

For safe passage, shipping traffic requires information, advice and instruction. In view of the need to manage the increasing complexity of maritime traffic, coastal States began to provide vessel traffic services (VTS) in the late 1940s.
1.2 Prevailing Trends

Today, there are well over 500 VTS operating around the world (IALA, 2016). The information and advice provided by VTS improves situational awareness (SA) for the safe conduct of navigation in VTS areas. Many times, these interactions have prevented potential collisions and groundings. In many marine incident investigations, VTS has been highlighted as an important bridge resource, contributing to the safety of navigation. The relationship between master, crew and VTS is inseparable. Multiple International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) VTS Guidelines and Recommendations have been developed on this basis; enhancing safety of navigation through improved human interaction.

VTS operation is constantly challenged in the rapidly changing maritime environment. From its first establishment with a single standalone coastal radar station in the 1940s, to the complex distributed systems of today - connecting large numbers of sensors and sub-systems. Human interaction between shore and ship is decreasing due to the availability of information via AIS, internet connectivity and high speed communication networks. Digitisation of information and other emerging technologies demand that VTS adopt new ways of traffic management.

Autonomous ships are an emerging disruptive technology that will impact the maritime industry (Pribyl & Weigel, 2018) and VTS is no exception. Autonomous ships will not be taking the high seas by surprise but will appear incrementally (Man & Rylander, 2016). As technology matures and produces a fault free track record, higher levels of autonomous ships with reduced manning will take to the seas. Thus, it is anticipated that manned ships will operate together with unmanned either autonomous or remotely controlled ships (Baldauf, Kitada, Mehdi, & Dalaklis, 2018). The mixed traffic scenarios seem to be especially challenging for future traffic management strategies.

E-Navigation is a concept developed by the International Maritime Organisation (IMO) and IALA. The concept is defined as "harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic
means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment.” (IMO, 2008). It will provide new technology, especially Information and Communications Technology (ICT) to enhance data exchange and communication between ship-shore-ship (Baldauf, Kitada, Mehdi, & Dalaklis, 2018). Although e-Nav is addressing the human operators ashore and on board, it also provides essential infrastructure to allow for autonomous systems and maybe even unmanned ships in the future.

1.3 Taxonomy

The terms autonomous and unmanned are rather new to the maritime industry. They are often used interchangeably. To differentiate the two terms, a distinction needs to be made. For the purpose of this dissertation, the definitions of the two terms are adopted from the American National Institute of Standards and Technology.

Definition of autonomous:
“Operations of an unmanned system wherein the unmanned system receives its mission from either the operator who is off the unmanned system or another system that the unmanned system interacts with and accomplishes that mission with or without further human-robot interaction”

Definition of an unmanned system:
“A powered physical system, with no human operator aboard the principal components, which acts in the physical world to accomplish assigned tasks. It may be mobile or stationary” (Huang, 2008).

Autonomous operation is further divided into various degrees of autonomies. Lloyd’s Register provides a guidance to describe autonomy levels (AL) ranging from ‘AL 0’ to ‘AL 6’ (Figure 1). It describes how autonomous ship operations might be carried out within the scale of 0 to 6. The ‘AL’ system of levels provides clarity to designers, shipbuilders, equipment manufacturers, ship owners and operators, enabling accurate specification of the desired level of autonomy in design and operations and
paves the way to a clearer understanding of the investment opportunity/risk equation (Lloyd's Register, 2016).

| AL 0: Manual | No autonomous function. All action and decision-making performed manually (n.b. systems may have level of autonomy, with Human in/on the loop.), i.e. human controls all actions. |
| AL 1: On-board Decision Support | All actions taken by human operator, but decision support tool can present options or otherwise influence the actions chosen. Data is provided by systems on board. |
| AL 2: On & Off-board Decision Support | All actions taken by human Operator, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off-board. |
| AL 3: ‘Active’ Human in the loop | Decisions and actions are performed with human supervision. Data may be provided by systems on or off-board. |
| AL 4: Human on the loop, Operator/Supervisory | Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human operators the opportunity to intercede and over-ride. |
| AL 5: Fully autonomous | Rarely supervised operation where decisions are entirely made and actioned by the system. |
| AL 6: Fully autonomous | Unsupervised operation where decisions are entirely made and actioned by the system during the mission. |

Figure 1: Autonomy levels (AL) adapted from Lloyd’s Register

DNVGL illustrates the relationship of the level of unmanned operation and autonomy to demonstrate the different types of autonomous operations (Figure 2). In traditional ships, autonomy level is at its lowest and the vessel is fully manned. On the opposite end of the spectrum, a fully autonomous vessel is where autonomy is at its highest
with no human on-board. Systems will be preprogrammed, just as today a pilot can follow a pre-recorded voyage plan. In addition, autonomous systems will contain a certain level of artificial intelligence and be able to detect and identify other vessels and do collision avoidance manoeuvres according to the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs).

Figure 2: Level of Autonomy and Unmanned Operation. Reprinted from “Autonomous vessels in a safety perspective” by Fosnavåg Shippingklubb, 2017. p.3. Copyright 2015 by the DNV GL.

1.4 Maritime Autonomous Surface Ships (MASS)

The development of autonomous ships in the past decade has been faster than envisaged. Marine technology companies such as Kongsberg Maritime and Rolls-Royce Marine are racing to put their concept of autonomous ships into full commercial operation (Tomotsugu, 2016). Whilst technological solutions are being developed and deployed, there is a lack of clarity about the correct application of existing IMO instruments to MASS. The use of Maritime Autonomous Surface Ships (MASS) creates the need for a regulatory framework for their interaction and co-existence with
manned ships. With regard to the human element, implications and effects of increased automation, both at sea and ashore, are relatively unfamiliar.

In February 2017, a proposal (IMO, 2017a) was submitted to the Maritime Safety Committee (MSC). It suggested MSC to consider undertaking a regulatory scoping exercise to determine how safe, secure and environmentally sound the operation of Maritime Autonomous Surface Ships (MASS) might be when introduced under existing IMO instruments. The co-sponsors believed that IMO needs to ensure that MASS designers, builders, owners, and operators have access to a clear and consistent regulatory framework in order to be able to demonstrate compliance with IMO instruments (IMO, 2017a).

The MSC supported the proposal and agreed to include it in the 2018-2019 biennial agenda of the MSC and the provisional agenda for MSC 99. The scoping exercise will identify current provisions in an agreed list of IMO instruments and assess how they may or may not be applicable to ships with varying degrees of autonomy and/or whether they may preclude MASS operations (IMO, 2018c).

In the MSC 99th session (May 2018), the committee endorsed the framework for a regulatory scoping exercise, including preliminary definitions of MASS and degrees of autonomy, as well as a methodology for conducting the exercise and a plan of work (IMO, 2018a).

To facilitate the process of the regulatory scoping exercise, MASS is defined as a ship which, to a varying degree, can operate independent of human interaction. The degrees of autonomy are organized as follows (IMO, 2018c):

i. **Ship with automated processes and decision support**: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated.

ii. **Remotely controlled ship with seafarers on board**: The ship is controlled and operated from another location, but seafarers are on board.
iii. **Remotely controlled ship without seafarers on board**: The ship is controlled and operated from another location. There are no seafarers on board.

iv. **Fully autonomous ship**: The operating system of the ship is able to make decisions and determine actions by itself.

The proposed regulatory scoping exercise would allow IMO to respond proactively to the growth in the use of MASS in a timely manner (IMO, 2017a). The exercise is also in accordance to Resolution A.850 (20) on the human element vision, principles and goals (IMO, 2003). In this way, the role and responsibility of VTS, as part of the entire spectrum of human activities contributing to the maritime safety and environment protection, should be considered.

### 1.5 Research Objective

Today, ships operating in the VTS area have a uniform means of interaction. International regulations and good seamanship have established a common understanding among seafarers for conduct of safe passage. The absence of seafarer on-board will affect the existing relationship of human to human interaction. Even though communication remains available between VTS and MASS, the absence of ship board personnel may strain existing operating procedures and system.

In accordance with IALA Guideline 1018 Risk Management on Hazard Identification, any number of internal or external events, including operational and technical changes would be identified as a possible hazard (IALA, 2013). The introduction of MASS is an external event which highly-probably will affect VTS operations and potential hazards must be identified. There is a need for VTS to adopt to a more resilient maritime safety culture by proactively adjusting performance prior to an introduction of a system (Hollnagel, 2015). This would indicate an early stage identification of problems or factors that may affect safety together with the development of regulatory actions before an accident occurs (Schröder-Hinrichs, Praetorius, Graziano, Kataria, & Baldauf, 2015; Praetorius, 2014). Therefore,
recognising the weaknesses and threats of MASS would prepare VTS for the challenges ahead.

This dissertation researches the potential effect of MASS on VTS operations. Firstly, the study will review the concept of operations (CONOPs) of MASS suggested by the industry and researchers. Limitations identified from scientific analysis will be examined against relevant IALA Guidelines and Recommendations to identify its impact to VTS work, e.g. procedures, technical and training of VTS Operators (VTSO). It is hoped that the result of this study might help the VTS Authority understand the potential impact of MASS to VTS operations, thereby establishing the necessary measures in VTS operating procedures and systems. The research will include the following:

- Examine related IALA VTS documents and existing technology used in VTS for traffic management,
- Review the CONOPs of MASS operations,
- Establish the relationship between MASS and VTS operations,
- Perform gap analysis to determine areas of potential risk, and
- Identify possible risk control options that VTS need to put in place for safe monitoring and management of MASS.
1.6 Structure of the Study

This dissertation covers 8 Chapters.

Chapter 1 introduces the background of the study, objectives and scope.

Chapter 2 gives an overview on the roles and functions of VTS. It describes the working relationship of manned ships with VTS.

Chapter 3 discusses the development of past and on-going MASS concept of operations. Three concepts were shortlisted for this study, based on their relevance and scale.

Chapter 4 describes the methodology used by the Istanbul Technical University (ITU) to identify factors in the weakness and threats of autonomous shipping. Factors were further evaluated on their relevance to VTS operations.

Chapter 5 and 6, involves gap identification and analysis of the factors identified in Chapter 4 which were used to highlight the potential downstream effect to VTS operations.

Chapter 7 presents the conclusion of this dissertation.

Chapter 8 recommends measures to prepare VTS operations for safe management of unmanned ship in VTS area based on the research.
2 BACKGROUND

The primary function of VTS is to promote efficient, safe and environmentally friendly maritime traffic movements in areas with high traffic density. These functions are carried out through interacting with ship masters and pilots to give them navigational information that supports the decision-making process on-board. This section gives an overview on the roles and functions of VTS. It describes the existing working relationship of manned ships and VTS.

2.1 Development of VTS

The world’s first VTS was established with a shore-based radar at the end of Victoria Pier, Douglas, Isle of Man, in February 1948. In July 1948, a port radar system was established at the Port of Liverpool. Thereafter, a number of shore-based radar sites were established around the world (IALA, 2016). The shore based radar system was installed in particular, for the interest of the safety of ships and increase the efficiency of traffic flow in port. This system pioneered the Vessel Traffic Services (VTS).

VTS service is legally defined by the IMO as a navigational safety measure in the International Convention on Safety of Life at Sea, 1974, as amended (SOLAS). In particular, the provisions in SOLAS regulation V/12 (Safety of Navigation) provides for Vessel Traffic Services, stating:

“Vessel Traffic Services (VTS) contribute to safety of life at sea, safety and efficiency of navigation and protection of the marine environment, adjacent shore areas, work sites and offshore installations from possible adverse effects of maritime traffic.”

In 1997, the IMO Assembly adopted IMO Resolution A.857(20) on Guidelines for Vessel Traffic Services to harmonize and create order to VTS. The Resolution describes the principles and general provisions for the operation of a VTS and participating vessels, in addition to the roles and responsibilities of Contracting Governments, Competent Authorities and VTS Authorities (IMO, 1997). This is
aligned with the United Nations Convention on the Law of the Sea (UNCLOS, 1982) on the minimal requirements for each member state to implement an information service within its territorial waters (UNCLOS, 1982).

The Resolution, in association with SOLAS chapter V Regulation 12, outlines the responsibilities and liabilities of Governments involved and gives guidance for planning and implementing a VTS as well as recruiting and training of VTSOs. SOLAS Regulation 12 states that: "Contracting Governments planning and implementing VTS shall, wherever possible, follow the guidelines developed by the Organization. The use of a VTS may only be made mandatory in sea areas within the territorial seas of a coastal state."

The requirements for VTS are considered by IALA. It is a non-governmental and non-profit technical association seeking to harmonise Aids to Navigation (AtoNs) worldwide. Its members are represented by AtoNs authorities, manufacturers, consultants, and other stakeholders in the maritime cluster. Members participate in the works of the VTS Committee to develop and review VTS related IALA documentations. The committee also reviews and updates the IALA VTS Manual, a comprehensive reference document which is published every four years (IALA, 2016).

Although IMO and IALA provide the recommendations and guidelines on the implementation of VTS, the legal obligation remains with the Competent Authority of a coastal State on the implementation and enforcements of VTS. IMO resolution A.857(20) states that “It is the responsibility of the Contracting Government or Governments or Competent Authorities to plan and implement vessel traffic services or amendments to such services.”
2.2 Functions of VTS

2.2.1 Safety and Security

VTS is mostly implemented in coastal waters where there are intense risks at shipping congestion points and at port approaches and estuaries. They are particularly valuable in managing shipping traffic by reducing risk of collision and grounding in high shipping traffic area such as the Straits of Malacca and Singapore, Turkish Straits and Dover Straits.

VTS is implemented in a predefined area. Vessels entering the area may be subjected to mandatory reporting as a form of identification. In some VTSs, vessels submit pre-arrival notification in advance to facilitate the reporting procedure. Data gathered are evaluated to improve VTSOs SA in real-time and future shipping traffic. At all times, VTSOs maintain good knowledge of the characteristic of the shipping traffic and potential risk. When necessary, VTSOs communicate with vessel to appraise master and crew of the developing situation ahead. With a complete picture on shipping traffic of the area, VTS information is an added advantage for master and crew to assess traffic around them.

While performing the above services, VTSOs also take on an enforcement role to ensure vessels comply with various national and international regulations. This helps to maintain order in shipping traffic, ensuring safety of navigation. Due to the increasing threat of terror and piracy attacks, coastal States see the benefit of VTS as part of coastal surveillance. Today, many VTS in the world are part of the security framework that safeguard the coast against potential attacks. VTS works closely with other enforcement agencies to detect illegal and suspicious activity.

2.2.2 Provision of Information

Beyond its safety and security functions, VTS contributes significantly to the efficient operations of a port. VTS is a local maritime information hub where information ashore and offshore are exchanged. This information can assist allied or other services with their own tasks (IALA, 2017a). In some VTS stations, information on pilotage, berthing
and tugs are communicated to vessels. Likewise, vessel arrival information—ETA, draft, and cargo information—are also communicated through VTS to the relevant shore party. The efficient facilitation of this information gives local ports a comparative advantage.

2.2.3 Coastal/Port Management

The increased volume of vessel arrivals for bunkering and supplies also strains the port authority to provide efficient spatial and temporal planning. VTS has the overview of the anchorage available for use and a good knowledge of vessel movements. Hence, they are able to manage vessels to port facilities and sea spaces more efficiently. Effective planning of the resources assures the port with higher economic benefit. Space planning also improves safe functioning of a port by segregating more dangerous vessels/operations from others. Port resources can be planned in accordance to the need of a vessel in advance. Similarly, vessel operators can plan their operations to meet the availability of port resources, thus minimising wastage of resources and energy, benefiting both port and vessel operators.

2.3 Type of VTS

There are two types of VTS developed for the uniqueness of shipping traffic in port and coastal waters. They are recognised as Port VTS and Coastal VTS. The two types of VTS serve specific functions in monitoring and management of shipping traffic. Port VTS is mainly concerned with vessel traffic to and from a port or harbour. In addition to promoting safe shipping movement, Port VTS ensures the economic profitability of ports. They facilitate efficient use of port resources by coordinating different port services and provide channel management for vessels to move within port safer and faster whereas, Coastal VTS is concerned with vessel traffic passing through the area and is usually an Information Service. Their objective is to provide information services that facilitate safe and expeditious passage for shipping.
2.4 Services provided by VTS

VTS provides three types of services - Information Service (INS), Traffic Organisation Service (TOS) and Navigational Assistance Service (NAS). The services are defined in IMO Resolution A.857(20) in conjunction with the recommendations issued by IALA. The aim of providing definitions and clarifications for the services is to achieve consistency in the provision of the services worldwide. This would avoid confusion to mariners trading between various jurisdictions. The VTS Authority implementing VTS needs to consider the services they will be providing in order to provide the necessary resources.

The INS provides information relevant to safe navigation to participating vessels in the VTS area. The VTSOs uses the Very High Frequency (VHF) to transmit the information to assist the on board decision-making process. VTS endeavours to deliver information that is timely, relevant and accurate.

The TOS is a service intended to support the efficient flow of traffic and manages space in the VTS area. Information transmitted as part of TOS might concern berth and channel clearances, assignment of anchorage, speed limits, or other information that can be used to organise traffic. Enforcement may also be carried out by the relevant Authority when VTS observed non-compliance of local rules and regulations.

NAS concerns the active support of the decision making process of a bridge team. A VTSO can provide NAS through transmitting advice, including the positions of other traffic movements, a vessel's course and speed, or warnings to a specific vessel. In comparison to INS, NAS signifies active participation in a bridge team’s navigation process. The VTSO not only transmits information, but also closely monitors its effect.
it will provide, as this will dictate the operating procedures, personnel and equipment requirements.

![Diagram of Vessel Traffic Services](image)

**Figure 3**: Type of services provided by VTS. Adapted from the VTS Manual (2016), Edition 6.

### 2.5 Technology use in VTS

A VTS area with more complex traffic movements and hazard to navigation would require more sophisticated equipment. Guidance on the operational and technical requirements of VTS Equipment can be found in the IALA Recommendation V-128. The Guideline provides information for the determination, operation and maintenance
of VTS systems (IALA, 2015). Equipment functions commonly used by VTS is explained in the following paragraphs.

Verbal communication between VTSOs and vessels form the basic function in the operation of VTS. VTS centres uses VHF, capable of working on the marine band, to communicate with vessels. A dedicated VHF Channel is declared to each VTS area for communication between VTS and the ship. VHF is also capable of transmitting digital information such as distress messages or calling a specific station as programmed (Digital Selective Calling - DSC). A VHF communication drawback is the relatively short working range, within line of sight radio.

Maintaining an overview of the traffic in the VTS area improves VTSOs’ SA of the ground. VTS centres uses a network of strategically located standalone marine radars, to track vessels within the VTS area. It is enhanced with automatic tracking capability (e.g. ARPA) to aid VTSOs to track vessels’ course and speed. Many VTS centres are using the Automatic Identification System (AIS) to aid vessel identification. This system makes use of a broadcast system that helps in updating data on connected vessels automatically. In an area where visual monitoring is required, VTS Centres deploy Close-Circuit Television (CCTV) to maintain visual contact.

Presentation of data and information is vital to improve the VTSO’s SA. To achieve this, data and information gathered from various sensors are integrated and presented on the Electronic Chart and Display System (ECDIS). Real-time traffic information super-imposed on ECDIS improves the VTSO’s SA of the traffic in relation to its surrounding. ECDIS is capable of continuously determining a vessel's position in relation to land, charted objects, aids-to-navigation, and unseen hazards.

2.6 Development at IMO Level

The existing IMO guidelines on VTS, IMO Resolution A.857(20), was adopted in 1997. In the past 21 years, there have been various organizational, operational, and technological developments taking place in the rapidly changing maritime domain. Recognising the need to validate the resolution to changes, member States, IALA and
others propose for a revision of resolution A.857(20) on Guidelines for Vessel Traffic Services (IMO, 2018b). This proposal was approved by the IMO’s MSC 99th session in May 2018 and tasked to sub-committee Navigation, Communications and Search and Rescue (NCSR) for action. With the introduction of MASS, it is expected that several proposed revisions will need to be set foundation to prepare VTS for the operational and technological changes ahead.

VTS operations need to adopt operational procedures that are objective and consistent. For instance, the resolution concept of “instruction” to vessels shall be “result-oriented” is subjective. VTS expert, Barry Goldman, opines that the term “result-oriented” can bring about differing interpretations (Goldman, 2018). He also discussed that “services” (INS, TOS and NAS) by VTS shall be described as functions of VTS rather than types of service. To support master and crew in their decision-making process, VTS operators are trained to provide traffic management service. The need to provide traffic information to master to resolve potential incidents must be objective, it shall not be limited by the form of “service” declared (Goldman, 2018).

Moving forward, VTS will adopt new technology to manage shipping traffic more efficiently. Likewise, there will be more automation on-board to carry out navigational tasks. These tasks which heavily rely on system to system interaction will require more objective technical and operational rules, and regulations in order to produce and ensure consistent results. Hence, this research aims at contributing to a profound foundation for the future development.
3 CONCEPTS OF MASS

Each MASS concept has its uniqueness in the area of study. They seek to address different challenges in the area of law, technology, fuel efficiency and cargo handling. In this chapter, several MASS concepts will be summarised from the interest of VTS operations. Based on their relevance and scale, three concepts were shortlisted for this study.

3.1 Development of MASS

Driverless transport systems are already state-of-the-art on certain transport legs. In the car industry, Google’s driverless car design, have self-driven over 8 million miles on American roads since 2009 (WAYMO, n.d.). In Copenhagen, driverless metropolitan trains have been servicing round the clock to over 61 million commuting passengers a year (Ansaldo STS, n.d.). Aerial drones were deployed to conduct certain tasks both in military and civilian fields.

In the maritime domain, autonomous operation is not uncommon. Autonomy has been tested on rather small vessels for both civilian and military use for two decades (Manley, Carlon, & Hine, 2017). More recently, in January 2018, the U.S. Defence Advanced Research Projects Agency delivered a prototype Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) for further trial. The unmanned vessel, christened Sea Hunter, is claimed to able to traverse thousands of kilometres over open seas for months at a time, without a single crew member aboard. (DARPA, n.d.). Operating subsea vehicles for research purposes have already been in practise for several years.

The MASS system is making way into commercial shipping for various reasons. The concept of unmanned ships is driven by safety of life, cost and the shortage in seafarers. A study by Rothblum found that about 75-96% of marine casualties are caused, at least in part, by some form of human error (Rothblum, 2000). This is driving the marine transportation industry, which is highly human intensive, to source for a safer solution – automation. Statheros and others believe that autonomous ship
navigation with intelligent algorithms for collision avoidance may possibly suppress
the navigational error to zero since they approach the collision avoidance problem in
a more objective way than humans (Statheros, Howells, & Maier, 2008).

Cost saving is attracting shipowners toward MASS as it could address crew shortage
and offer financial saving with reduced crew on board (Burmeister H.-C., Bruhn, Rodseth, & Pørath, 2014a). In March 2013, the executive vice president of Det Norske Veritas and Germanischer Lloyd (DNV GL), Bjorn Haugland, wrote that unmanned ships are a potential game changer. He relates unmanned ships to 10 benefits, such as lower operational costs, elimination of on-board crew cost, risk associated with human error and threats to crew safety.

"Unmanned shipping has a huge potential to drive economic, environmental and social sustainability in the shipping industry and I am happy to see a lot of exiting development taking place in the industry these days." (Haugland, 2016)

In the annual Futurenautics Global High level Roundtable discussions that took place in Aalesund, Norway, 2016. Mr Oskar Levander, Vice-President Innovation of Roll-Royce Marine, pointed out that the impact of unmanned shipping is far wider than just removing the crew cost. He gave the example of an unmanned bulker, which could potentially save up to 15% in fuel cost for energy consumption on sustaining the crew on board (Futurenautic, 2015).

The Roundtable discussion concluded that autonomous or unmanned ship is an unavoidable emerging technology. This is due to digitisation that has profoundly integrated ships into the global blue logistics system (Futurenautic, 2015).
3.2 MUNIN

Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) was launched and funded by the European Commission (EC) in 2012 and was completed in 2015. Over a 3-year period, its consortium consisted of eight partners from scientific and industrial backgrounds located in Germany, Norway, Sweden, Iceland and Ireland. The objective of the MUNIN was to develop and verify the concept of autonomous merchant ships. Research partners dealt with the technical and legal aspects of the project. While industry partners represented the different business areas of the ship supplier market and ensure a close relation to market demands (MUNIN, n.d.).

Rodseth and Tjora described an unmanned merchant ship as a form of an "industrial autonomous system" (Rødseth & Tjora, 2014). The system must be reliable and cost effective following a systematic, but pragmatic approach to overall design. MUNIN concepts involve new sensor systems, new technical operation and maintenance procedures, autonomous navigation functions as well as a new shore control centre (SCC) and other components. The important part of the project is to develop a system architecture that interconnect all the new modules. Its challenges include addressing the various constraints related to safety and security of the system as well as highly variable quality of service (QoS) for ship to shore communication channels (Rødseth & Tjora, 2014).

The case study investigated in MUNIN was a dry bulk carrier of 75,000 dead weight tonnes with a service speed of 16 knots, operating unmanned in intercontinental tramp trades. Autonomous operation of the vessel was only during deep-sea-voyage. The ship was under control by on-board crew in congested waters and those approaching, and leaving harbour. The aim was that the ship would be autonomous and unmanned from pilot drop-off point to pilot pick-up point (MUNIN, 2016). There may be maintenance teams or other personnel on-board as and when required. If serious problems occur, an emergency control team (ECT) may be needed during passage. ECTs can board and disembark from shuttle boats or from helicopters (Rødseth &
Tjora, 2014). The following picture (Figure 4) shows how the concept of MUNIN’s autonomous vessel would work.

![Figure 4: MUNIN Operational modes. Reprinted from “MUNIN Result”. Retrieved from http://www.unmanned-ship.org/munin/wp-content/uploads/2015/10/MUNIN.jpg. Copyright 2016 by the Fraunhofer CML.](image)

The proposed relationship with various parties involved in the interaction with unmanned ship is illustrated in Figure 5. The autonomous operation at high sea is

![Figure 5: Illustration of unmanned ship context. Adapted from “A system architecture for an unmanned ship” by Rodseth and Tjora.](image)
primarily guided by automated on-board decision systems but monitoring and controlling functions would be executed by an operator from a control centre ashore known as the Shore Control Centre (SCC). The dashed lines illustrate that there may be direct contact between the SCC and other parties. When necessary, unmanned ship will interact with VTS and other ships.

The following are the systems and entities defined in MUNIN (MUNIN, 2016):

- An Advanced Sensor Module, which takes care of the lookout duties on board the vessel by continuously fusing sensor data from existing navigational systems, like e.g. Radar and AIS, combined with modern daylight and infrared cameras;

- An Autonomous Navigation System, which follows a predefined voyage plan, but with a certain degree of freedom to adjust the route in accordance with legislation and good seamanship autonomously, e.g., due to an arising collision situation or significant weather change;

- An Autonomous Engine and Monitoring Control system, which enriches ship engine automation systems with certain failure-pre-detection functionalities while keeping the optimal efficiency and which takes care of the additionally installed pump-jet that acts as a certain rudder and propulsion redundancy;

- A Shore Control Centre (SCC), which continuously monitors and controls the autonomously operated vessel after its being released from its crew by its skilled nautical officers and engineers. It comprises amongst others the certain positions:
  - A SCC Operator, who monitors the ship operation of several autonomous ships at the same time from a desktop cubicle station and controls the vessels by giving high level command like, e.g., updating the voyage plan or the operation envelope of the autonomous system;
- A SCC Engineer, who assist the operator in case of technical questions and who is in charge of the maintenance plan for the vessels based on a condition-based maintenance system ensuring sufficient reliability of the technical system for the next autonomous journey;

- A SCC Situation Room Team that can take over direct remote control of one vessel in certain situations via a shore side replica of the unmanned vessels bridge including a Remote Manoeuvring Support System that ensures an appropriate situation awareness in direct control despite the physical distance of crew and vessel.

The study found that by giving a proper operational and robust system, risk of collision and foundering can be decreased by ten times compared to manned shipping, mainly due to the elimination of fatigue. In addition, risks of engine and other system breakdowns are expected to be lower for unmanned ships if proper redundancy is implemented and improved maintenance and monitoring schemes are followed. The possibility of fire and explosion can be reduced with the use of more efficient extinguishing systems in fully enclosed spaces (MUNIN, 2016). Furthermore, MUNIN's approach of installing an autonomous acting system on the vessels also facilitates implementing fail-to-safe-functionalities on board, which ensures safety of navigation and operation during possible communication disconnections (Rødseth & Tjora, 2014).

The MUNIN project has identified the overall framework and several technical solutions to operate MASS safer and more efficiently at high sea and in coastal waters. Their proposal includes using advance modular control systems and communication technology to enable wireless monitoring and control, including advanced decision support systems and the capabilities for remote and autonomous operation (MUNIN, 2016). However, there are challenges that remain to be solved.
3.3 ReVolt

DNV GL initiated a research project with the name ‘The ReVolt’ in August 2013 (Figure 6). It was launched in the succeeding year 2014. An international certification body, the organisation primarily deals with the assessment, risk management, advisory function, and provides technical support (DNV GL, n.d.-a). The ReVolt is a concept ship which would be completely handled by a battery system and would be fully autonomous. Due to limited power, it is designed for short sea voyages in the range of 100 nautical miles before the battery needs to be recharged. Using batteries would reduce the operating costs by minimising the number of high maintenance parts such as rotational components. There would be far fewer emissions from the vessel, especially if it is recharged from renewable power sources (DNV GL, n.d.-b).

![Figure 6: Concept design of The ReVolt. Adapted from website: https://www.dnvgl.com/technology-innovation/revolt/index.html. Copyright 2018 by the DNV GL AS.](image)

EU is currently suffering with the issue of congestion and the population growth in urban areas. This will lead to a demand for transportation that exceeds the capacity of existing roads. To alleviate these issues, governments all over EU are trying to move some of the freight volume from roads to waterways. The concept of the ReVolt provides the solution of short sea shipping, which diverts some of the transportation volume from rail/roads to the sea channels (DNV GL, n.d.-b).
The ReVolt is a vision for the future and will not be built until several of the technologies involved have matured. For the purpose of testing the autonomous capabilities of ReVolt, a 1:20 scaled model has been built. Through collaboration with the Norwegian University of Science and Technology (NTNU), this model will serve as test bench in researching sensor fusion and collision avoidance for autonomous surface vehicles. This competence project will run for three years from Q3 2015.

3.4 Advanced Autonomous Waterborne Applications Initiative (AAWA)

The AAWA consortium is a national Finnish project. The project is funded by the TEKES (Finnish Funding Agency for Technology and Innovation), which aims to produce the specification and preliminary designs for the next generation of advanced ship solutions.

AAWA brings industry partners together with universities, research institutes, ship owners and other stakeholders to explore the economic, social, legal, regulatory and technological factors which need to be addressed in order to make autonomous ships a reality. The project is led by Rolls-Royce together with DNV GL, Inmarsat, Deltamarin, NAPA, Brighthouse Intelligence, Finferries and ESL Shipping. The participating companies aim to spread remotely monitored and remotely operated technology to the market and to continue to higher levels of autonomy within a number of years (Jokioinen, 2016).

The first phase of AAWA project explored the current state of understanding of the technological, safety, legal and economic aspects of a remote, and autonomous operation. The initial conclusion are as follows (AAWA, 2016):

1. There will be no single remote or autonomous ship solution but rather a hybrid of the two which will depend on the type and function of the vessel.

2. The technologies needed to make remote and autonomous ships are a reality that exists. The challenge is to find the optimum way to combine them reliably
and cost effectively. The development on decision support systems for autonomous vessels will be a gradual and iterative process and subject to extensive testing and simulation.

3. The operation of remote and autonomous ships will be as least as safe as existing vessels. There is potential to reduce human based errors but at the same time new types of risk will arise and will need to be identified and addressed.

4. Legislation can be changed if there is a political will. For remote and autonomous shipping to become a reality effort is needed at all regulatory levels. The legal challenges of constructing and operating a demonstration vessel at a national level need to be explored whilst simultaneously considering appropriate rule changes at the IMO. Questions of liability for autonomous ships are subject to national variations, but generally it seems that there is less need for regulatory changes in this field. What needs to be explored, however, is to what extent other liability rules, such as product liability, would affect traditional rules of maritime liability and insurance.

5. Remote and autonomous ships have the potential to redefine the maritime industry and the roles of players in it with implications for shipping companies, shipbuilders, maritime systems providers and technology companies from other (especially the automotive) sectors.

The next two phases of AWWA will build on the findings from the first phase, to develop the technical, legal, and safety specifications for proof of concept.

Phase II will include development and testing of specific technological solutions using simulators and tests at sea across a variety of environmental conditions. Building on the marine industry’s experience of systematic and comprehensive risk assessments to identify new risks, the project will continue to explore potential legal challenges of constructing and operating a demonstration vessel at a national level whilst
simultaneously considering appropriate rule changes at the IMO. Lastly, it would seek to establish cost and revenue models by seeking stakeholder views.

Rolls-Royce aims to produce a full scale commercial demonstrator in Phase III by embedding smart ship equipment into an existing vessel. The company envisages a remotely operated local vessel in the first stage and in operation by 2020. By 2025, Rolls-Royce hopes to have a remotely operated autonomous vessel in international waters. In five years, Rolls-Royce hopes that autonomous ocean-going vessels are a common sight on the ocean (Figure 7). As time goes on, such ships will become ever more intelligent and capable of more advanced autonomous operation.

4 RESEARCH METHODOLOGY

The concepts of autonomous ships are largely suggested in theory. Thus far, there are no real experiences gained on the effect of autonomous ships interacting with manned ship and VTS. As research methodology, the researcher used a literature-based theoretical analysis in combination of qualitative assessments conducted on autonomous shipping.

4.1 Method

It is recognised that current VTS operations do not consider management of MASS. Henceforth, VTS will need to adopt new operational procedures and technology to manage MASS safely. The researcher uses Gap Analysis to assess the difference between current VTS operations and the future. Gap Analysis is a strategic tool to determine what steps need to be taken in order to improve the current state to a desired, future state.

To identify the potential gaps, the researcher takes the results as reference attained in the scientific analysis of SWOT-AHP from the Istanbul Technical University. Factors identified in the analysis are used to guide the researcher to identify potential gaps.

Factors identified in the SWOT analysis are aimed at identifying the strengths and weaknesses of an operation, and the opportunities and threats in the environment for autonomous shipping. These factors could also pose a potential latent condition for MASS accidents occurring in the VTS area. Thus, analysing the weaknesses and threats in autonomous shipping to help identify the gap is critical.

The SWOT-AHP analysis was conducted to qualitatively identify and evaluate the strengths, weaknesses, opportunities and threats of autonomous shipping (ŞENOL, GÖKÇEK, & SEYHAN, 2017). Factors were further evaluated on their relevance to VTS operations.
As part of the gap identification process, the researcher participated in a simulation study (Baldauf, Mejia Jr., Chong, & Amphanthongpaphakul, 2018). The simulation was conducted by Professor Michael Baldauf of the World Maritime University (WMU). It aimed to study the different equipment options for monitoring and the remote controlling of an unmanned ship. Participation in this exercise provided a more realistic experience for the researcher to understand human element related issues on VTS and manned ships interaction with SCC operators.

The approach of the research is summarised in Figure 8 below;

![Research Methodology](image)

**Figure 8: Research Methodology**

### 4.2 Hypothesis

There are numerous literature works on the MASS concept of operations. These concepts described MASS operation with varying levels of autonomy. The application of different levels of autonomy is dependent on the complexity of the environment. In MUNIN, the concept suggests an autonomous ship to be manned during passage in
congested waters and approaching port (MUNIN, 2016). Whereas, the ReVolt concept suggests the vessel to be fully unmanned and controlled remotely regardless of the density of traffic and complexity of the environment (DNV GL, n.d.-b). Nonetheless, it may be expected that ship managers would want to operate MASS autonomously as long as possible to exploit full advantage of autonomy and not involve additional cost (Wróbel, Montewkab, & Kujałac, 2017).

A remotely-controlled unmanned ship is envisaged to sail among vessels in 2025 and a fully autonomous unmanned by 2035 (DNV GL, n.d.-b). Due to the closer timeline of the former to operate among shipping traffic, the hypothesis of this study is based on remotely-controlled ship without seafarers on board: The ship is controlled and operated from another location. Hence, interaction will only be carried out between shore-based operator and VTS.

4.3 Limitation

The time limit kept the researcher under pressure to keep the scope of the research limited.

Autonomous systems have been widely discussed in the transportation industry. With the first definition made by IMO in May 2018, MASS is in its infancy stage. Thus far, there are few studies on MASS interaction with shore-based support ship-handling carried out (Baldauf, Kitada, Mehdi, & Dalaklis, 2018; Man, Lundh, & Porathe, 2014). They aimed to analyse the challenges from having the operator on-board to onshore during ship manoeuvring and explores the changing aspects of human factors. These studies were carried out using simulation study and focus group interviews.

However, there is lack of applicability for the concept of real unmanned ships towards VTS operations, the data gathered is mostly conceptual and based on the ideologies and of real time.
Literature reviews of this study are based on the existing concept of autonomous shipping. It is foreseen that rapid technological developments will address some of the challenges highlighted in this research.
5 GAP IDENTIFICATION

Based on the concepts proposed in the three MASS projects, it is anticipated that current VTS operations will not be adequate to support. Therefore, it is crucial to identify areas of improvement for VTS to adjust its performance to meet future needs. This section identifies the gaps using relevant SWOT factors that might potentially affect VTS operations.

5.1 SWOT-AHP Analysis

SWOT analysis is a commonly used strategic planning method to evaluate the Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T) of an organisational and operational system. The approach involves systematic thinking and comprehensive diagnosis of factors relating to a new product, technology, management, or planning (Weihrich, 1982). By identifying these factors (Figure 9), new constitutive strategies can be developed based on strength, elimination of weaknesses, exploiting of opportunities and counteracting the threat (Saaty R., 1987). However, the limitation of SWOT analysis in decision making cannot be measured

![Figure 9: SWOT Table. Adapted from “Swot-Ahp Analysis of Autonomous Shipping” by Y. E. ŞENOL, V. GÖKÇEK and A. SEYHAN, 2017. 4th International Multidisciplinary Congress of Eurasia Proceedings, Volume 2, p.60.](image-url)
quantitatively. As such, it is difficult to assess which factor influences the strategic decision most (Görener, Toker, & Uluçay, 2012).

The Analytic Hierarchy Process (AHP) is a technique used to perform pairwise comparisons between evaluation factors in order to prioritise them. AHP is an effective tool for decision making and helps the decision maker to set priorities (Sharma, Moon, & Bae, 2008). It also incorporates technique for checking the consistency of the decision maker’s evaluations, thus reducing biasness (Saaty T., 2008).

The combination of SWOT and AHP analysis will systematically qualify SWOT factors and equate their intensities (Wickramasinghe & Takano, 2009). This enhanced method has been broadly applied and studied in various fields, including maritime area; formulate the strategy of the safe carriage of bulk liquid chemicals in tankers (Arslan & Deha Er, 2008), analytical investigation of marine casualties at the Strait of Istanbul (Arslan & Turan, 2009), shipping registry selection in maritime transportation industry (Kandakoglu, Celik, & Akgun, 2009).

Istanbul Technical University (ITU) used the SWOT-AHP to identify SWOT factors and determine their priorities. The data related to the study were gathered by online and face to face expert consultations. Inputs of AHP are gathered from multiple sources such as field experts, shipowners, experienced captains, shipping companies’ operational manager and academicians. ITU made a survey and asked respondents to critic autonomous shipping and then rate the determined factors for each step (ŞENOL, GÖKÇEK, & SEYHAN, 2017). The strengths, weaknesses, opportunities and threats of autonomous ship were given as internal and external factor groups in Figures 10 and 11.
Figure 10: Internal Factors. Adapted from "Swot-Ahp Analysis of Autonomous Shipping" by Y. E. ŞENOL, V. GÖKÇEK and A. SEYHAN, 2017. 4th International Multidisciplinary Congress of Eurasia Proceedings, Volume 2, p.62.
Figure 11: External Factors. Adapted from “Swot-Ahp Analysis of Autonomous Shipping” by Y. E. ŞENOL, V. GÖKÇEK and A. SEYHAN, 2017. 4th International Multidisciplinary Congress of Eurasia Proceedings, Volume 2, p.62.
5.2 Factors Affecting VTS Operations

The study from ITU reveals the strengths, weaknesses, opportunities and threats of MASS. Areas that were perceived as providing the most prominent impact to safety to the maritime system were Weaknesses and Threats. These areas are most likely the potential latent conditions for future marine accident of MASS. As such, risk control measures should be considered to strengthen these weaknesses and eliminate threats.

For the purpose of this dissertation, factors within the Weakness and Threat of MASS are further evaluated. Based on the relevance to VTS operations, these factors are studied on its effect on safe and efficient management of vessels in a VTS area. The study of these factors would increase awareness on the risk of introducing unmanned ships in a VTS area and the need to establish safety barriers. The criteria for considerations are as follows:

a) Risk to safety of navigation in a VTS area;
b) Interaction with VTS; and,
c) Communication and information exchange between vessel and VTS.

Factors identified to influence the safe operations of VTS from the Weakness and Threat of autonomous ship are as follows (Figure 12):

<table>
<thead>
<tr>
<th>Lack of Emergency Responses: In case of emergency situations such as fire, collision and grounding, unmanned ships are vulnerable to worsen the situation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need for Qualified Personnel: When needs for seafarers are reduced, there is a need for new concept oriented crew who necessitates heavy training programs.</td>
</tr>
</tbody>
</table>
**Software Reliability:** Recent studies are not capable of transporting goods as safely as the traditional way yet. This aspect of autonomous ship idea leads to a challenge in terms of reliability.

**Encounter with Manned Ship:** Uncertainty on communication and agreement method between manned and unmanned ship may lead to risky conditions.

**Cyber Attacks/Piracy:** If security of the software is not ensured proactively, probable piracy attacks may threaten not only marine safety but also security of societies living alongside the sea.

**Adoption of Marine Regulations:** Legal boundaries of an autonomous ship is not identified precisely yet. Therefore, adoption of regulation could be difficult. Autonomous ship needs big revolutions on rules and regulations.

Figure 12: Factors with potential impact to VTS operations. Selected from “Swot-Ahp Analysis of Autonomous Shipping” by Y. E. ŞENOL, V. GÖKÇEK and A. SEYHAN, 2017. 4th International Multidisciplinary Congress of Eurasia Proceedings, Volume 2, p.67-68.

5.3 Planning and Conduction of a Pilot Simulation Study

Simulation studies were carried out using certified full-bridge simulator in the WMU (Baldauf, Mejia Jr., Chong, & Amphanthongpaphakul, 2018). The scenario was based on a transit passage of a remotely controlled unmanned container ship through the German Bight VTS-monitored area. Participants involved as SCC operators were experienced seafarers and personnel from the maritime domain.

The simulation plan was designed assuming a scenario with an unmanned ship which autonomous mode were failing to smoothly function and the SCC operators had temporarily to take over remote-control from the SCC. The traffic scenario was created using historic AIS/radar data from a VTS service, and consisted of more than 15 targets in the sector of concern. The simulation scenario’s environmental conditions were daylight with good visibility, moderate wind, calm-sea state and no current.
The VTS coverage related to the traffic flow was integrated by VHF communication and was integrated in all simulation runs. VTS communication included regular standard weather and traffic reports. The participants in the SCC could listen to the reports but were unable to communicate with the VTS station as well as with targets.

All participants were briefed on the situation and voyage plan of the unmanned ship. They were to sail the vessel remotely to a fixed destination point. The simulated control centre was equipped with complete bridge equipment, including a bridge view out of the window simulated as remotely transmitted video signal.
6 ANALYSIS

The factors affecting VTS operations identified as gaps are further analysed in this chapter. The analysis considers how the gaps identified from weakness and threat of autonomous shipping might affect VTS operations. They are evaluated against various IALA Guidelines and Recommendations, and potential scenarios involving VTS while interacting with unmanned ships.

6.1 Lack of Emergency Responses

Today, VTS responds to marine emergencies by facilitating information exchange between ship and emergency services. During an emergency, crew would describe the situation on board to the VTS and request for the necessary assistance, and resources. This information is conveyed to emergency response services ashore for the necessary arrangement. Depending on the gravity of the situation, the VTS may help broadcast the distress to nearby ships for their immediate assistance. Efficient interaction between VTS and crew expedites, and improves utilization of emergency resources.

Maritime emergency includes among others, collision, capsize, sinking, grounding, fire, man overboard, oil pollution, medical emergency and vessel not under command (NUC). On manned ships, response towards such emergency situations are carried out by the crew. Their role is to stop the damage from escalating and to mitigate further risks.

According to a study on the potential impacts of unmanned ships on maritime transport safety, it was found that the extent of the consequences resulting from non-navigational accidents (e.g. fire, ship loss due to structural failure) can be expected to be much larger (Wróbel, Montewkab, & Kujalac, 2017). This is due to the lack of crew to assess and carry out damage control. From the observations of the simulation trials, it could be observed that SCC operators will also have limited information of the conditions on board and would be unable to accurately describe the assistance required unless more data than provided in the simulation experiment is provided.
Perception and cognition are the keys in a ship sense from the perspective of human factors (Prison, Dahlman, & Lundh, 2013; Porathe, Prison, & Man, 2014). The absence of crew on MASS will be a challenge for VTS to gather the information, assess the situation and decide what type of assistance is required. The loss of human connection to the elements would result in an inaccurate assessment of the emergency situation. Furthermore, it will be difficult for the SCC operators to perceive the situation remotely, and understand the surrounding environment the vessel is facing.

Recognising that the consequences can be high in an unmanned ship accident, the VTS would need be familiar with the concrete emergency and incident management procedures (IALA, 2016). These will include allied services who are able to render emergency services. In a collision situation, when SCC operators do not have visual and data about the condition of the damage, or whether the impact has breached any structural integrity, the VTS, e.g., would have to seek assistance from ships within the vicinity or other technical equipment like e.g. drones to provide information on the extent of damage. Thereafter, coordinate with the appropriate allied services to provide emergency response.

An area of concern for VTSOs, is to maintain a safe waterway throughout the emergency. Although MUNIN will have provision for fail-to-safe mode (Rødseth & Burmeister, 2012) the critical issue will be for autonomous systems to establish its safe mode in relation to the traffic and environmental conditions. Unmanned ship shall not assume safe mode in regards to own perspective but towards the safety of all ships and the environment. VTSOs who have better situational awareness of the VTS area must consider his/her navigational assistance role to provide a safe place of refuge in times of emergency.

On the other hand, an AAWA’s study has found that increased sensor data on unmanned ship could reproduce information to authorities if needed. Video and sensor data could be transmitted directly to vessel traffic monitoring services, which could be helpful in increasing the authorities’ SA in emergencies (AAWA, 2016). Thus,
VTS should develop an information exchange framework with SCC as part of an incident management plan. This information will be valuable for incidental co-operation between the VTS and emergency services.

Above all, prevention is better than cure. Wróbel and others (2017) felt that preventing accidents from occurring appears to be a better idea than counteracting its consequences (Wróbel, Montewkab, & Kujalac, 2017). Therefore, the VTS plan of actions should be aimed at reducing the occurrence of accidents. Risk control measures must be implemented based on incidental prevention and combined with well-prepared operational procedures.

6.2 Need for Qualified Personnel

Porathe and others (2014) have identified that human error remains the biggest challenge even on remotely controlled ships. In particular, how does one achieve the same SA on board as manned ships? Future officer-of-watch may be responsible for a fleet of ships from a shore-based control centre with the additional challenge of having to analyse and respond to situations as they develop miles away. Furthermore, new challenges created by the “human-out-of-the-loop” syndrome may result in delays in decision making (Porathe, Prison, & Man, 2014). It is anticipated that SCC operators will need to possess a unique set of skills to overcome these challenges.

The simulation studies showed apparent differences in the action taken between the experienced navigators and non-experienced personnel to avoid collision. Experienced navigators used all navigational equipment that were available to improve their SA. Coupled with good knowledge of COLREGs, they manoeuvred the ship in a more calculated manner and observed the response carefully. Whereas, the non-experienced personnel were dependent on less equipment for information and their manoeuvring, rather drastic. It was deduced that personnel with seafaring experience were more forethought.
Feedback gathered from participants further revealed their decision-making process. As SCC operators were not able to communicate through VHF, experienced navigators felt that they were restricted to acquire more information for decision-making. They believed that if they were able to communicate with VTS and manned ships, action to avoid collision could be taken earlier. It was further commented that information from ECDIS, radar and bridge view were crucial for them to gain SA to control the vessel remotely. However, non-experienced navigators did not feel that communication was important and could contribute to decision-making.

Experienced navigators tend to apply the concept of Bridge Resource Management while navigating. They sourced information more widely. These were not limited to VTS’s assistance to improve their SA. Whereas, personnel with no seafaring experience did not see the need. The exercise demonstrated that the background of SCC operators would potentially influence the interaction with VTS.

VTSOs have long established a cooperative relationship with mariners and maintain a shared mental model. Together, they function as a team to achieve a common goal. Working with SCC operators and adapting to new technology will be a new experience. SCC operators will apply a different set of skills and knowledge to manage the operation risk of MASS (Man & Rylander, 2016). With the change in team dynamics, this cooperative mechanism will need to be studied to optimise people performance (Han & Ding, 2013). VTSOs will need to familiarise themselves with the conditions and constraints of SCC operators. This will enable VTSOs to form a shared mental model when managing MASS.

The nature of MASS operations is unique from the conventional management of shipping traffic. This requires VTSOs to be appropriately trained before they undertake the duties associated with the type of services provided (IALA, 2017c). VTS Authorities will need to study the new method of traffic management where MASS operates among manned vessels. VTSOs will need to be familiar with the technical know-how in order to operate the new system.
6.3 Software Reliability

On a conventional ship, risk to safety of navigation due to software failure is negligible. There is always the master and crew to take over and steer the ship to safety. They have the ability to adapt to unforeseen and surprising situations. Whereas on MASS, the system and software lack the ability to adapt to unforeseen situations (Ahvenjärvi, 2016). Rolls-Royce has identified that technological reliability is the biggest challenge faced in the development of unmanned ships (Futurenautic, 2015).

System and software are considered the “heart” of an unmanned ship. Therefore, MASS experiencing software failure in the VTS area will not be a trivial matter. The failure can significantly impact the safety of navigation to other vessels in the VTS area. SCC operators need to have full awareness of the health of the system on board and be able to detect any anomaly immediately. Delayed information on system/software failure could result in catastrophic events.

In MUNIN, the situation is catered for by a fail-to-safe mode which responds to situations that might undermine the safe navigation of the ship. If the communication between the ship and SCC fails, or if technical problems make it impossible for the SCC to solve it, the ship will go into a fail-to-safe state. Depending on the environment, the fail-to-safe state can mean different things, e.g. in trafficked waters the ship will “heave-to”, i.e. with the engine and rudder standing still, bow to the wind, or close to land, anchoring (Kretschmann, et al., 2015).

While addressing MASS software reliability, the VTS must consider the system it requires to support the interaction with MASS. Bearing in mind that the VTS needs to ensure that the technical and operational performance of the VTS system meets the operational objectives set. Therefore, an equivalent robust system and software that are able to sustain uninterrupted communication with MASS are essential. IALA Recommendation V-128 on Operational and Technical Performance of VTS Systems recommends “A VTS system should provide the capability to monitor traffic within the VTS area, interact with the vessel traffic and respond to developing situations in a manner that enables the objectives of the VTS to be achieved.” (IALA, 2015).
MASS will need to transmit enormous amounts of data collected from various sensors in real-time to/from shore (Kobyliński, 2018). The amount of data will significantly increase through passage where shipping traffic is expected to be more complex and risk to navigation is high. It is anticipated that the VTS’s interaction with MASS will be required to transfer large amounts of navigational data continuously and vice versa. Such voluminous data of communication will not be practicable to communicate over satellites. Therefore, the VTS will need to provide the necessary infrastructure around the coast with sufficient bandwidth to support the data exchange. The availability, reliability and security of this network is important to support the communication.

The VTS needs to ensure both MASS and its system/software failure does not impact to safe operations of traffic movement in the VTS area. They should be familiar with the potential scenarios that may developed when a system/software failure occurred. In so doing, VTSOs should be quick to provide the necessary support to SCC operators and disseminate information to alert other ships. In the scenario when the communication link between SCC and MASS is disconnected, the VTSO must decide and act pro-actively to prevent an incident from developing. This may require the VTSO to take over some form of control.

6.4 Encounter with Manned Ship

Another issue causing the most concern is the interaction between unmanned and manned ships (Burmeister H.-C. , Bruhn, Rødseth, & Porathe, 2014). Voice communication using VHF radio remains commonplace in ports, used for ship-to-ship communication and VTS centres to exchange information. Harmen van Dorsser, nautical innovation adviser at the Port of Rotterdam, shared his concerns on the ability of unmanned ship to communicate with others (Cousins, 2017). He felt that given the complexity of shipping traffic in port, autonomous ships may find it impossible to communicate and navigate safely.

To experience the importance of communication between SCC and manned ships, the simulation studies did not provide VHF to SCC operators for communication
(Baldauf, Mejia Jr., Chong, & Amphanthongpaphakul, 2018). It was gathered that they were compelled to use VHF to communicate especially when the traffic situation became demanding. Experienced seafarers felt that voice communication is essential, effective communication would improve safe interaction with other ships (Norris, 2015). In MUNIN, it was stated that communication calls will be relayed to the SCC from which the human operator will reply (Rødseth & Kvamstad, 2012).

The Norwegian Forum for Autonomous Ships defines that communication equipment must be linked to the SCC to facilitate voice communication with other ships or shore entities when the bridge is unmanned. It is envisaged that SCC located on land would have access to high capacity communication lines. SCC may also have direct connection to other shore entities or even ships via digital communication, e.g. over internet or satellite connections (Rødseth & Nordahl, 2017). Assuming all means of communication between MASS and manned ships is replaced with digital information, VTS must be able to monitor the communication to maintain SA.

Mariners also use other means of communication to interact, such as applying the lights, shapes and sounds prescribed in the COLREGs, and signals in the International Code of Signals. These signals are used to communicate among vessels to make their intention and status clear. An unmanned ship's ability to display some of these signals may be restricted, and this would affect the interaction with manned ships. The potential limitation of MASS to effectively communicate with manned ships is a risk to safety of navigation. This risk increases when there is more interaction between vessels especially in a VTS area.

Interaction between MASS and manned ships will open new means of digital communication. Therefore, the VTS would need to consider its existing means of communication to ensure information exchange between vessels and VTS is not compromised. Bearing in mind that IALA R1012 on VTS Communication states “…VTS communications are harmonised through common phraseology, procedures and technology for the delivery of precise, simple and unambiguous communications to the bridge team and allied services.” (IALA, 2017b).
With the potential change of communication with MASS towards digital communication, VTS should be obliged to provide new services using digital formats. These services include information on waterway condition, weather, hazards or any other factors that may influence the vessel's transit. The provision of this information should comply among others with IMO Resolution A.706(17), as amended, – World-wide navigational warning.

6.5 Cyber Attacks/Piracy

In a Nautilus’s survey to seek maritime professionals’ views on autonomous ships, cyber security is rated as the main obstacles to the adoption of unmanned ships (Nautilus Federation, 2018). AAWA whitepaper expressed concerns over hacker activity, particularly around communication and navigation technology, but has not given a comprehensive cyber-risk analysis (AAWA, 2016). In a cyber-risk assessment for autonomous ships, it was found that the most at risk systems for the future are AIS (Balduzzi, Wilhoit, & Pasta, 2014), GNSS, and the growing interconnected networks of sensors. The assessment found these systems to be prone to several scenarios of attacks, such as counterfeiting data in AIS information, Denial of Service (DoS) by blocking operational commands and sensory data of satellite communication . (Tam & Jones, 2018).

In some parts of the world, manned ships face a higher risk of a pirate attack. In the first quarter of 2018, there were 66 piracy attack incidents and 100 crews were reportedly held hostage (IMB, 2018). The concern of crew safety in a pirate attack is drawing the interest for ships to go unmanned. Although an unmanned ship eliminates the risk of crews being attack by pirates, the reliance on technology is exposing it to another form of piracy attack – cyber-piracy. Cyber-piracy attacks will no longer be limited by geographical area but by vulnerabilities of a system. Pirate-hackers may take control of an unmanned ship or hack into port information systems to guide the ship to carry out attacks.

Cyber-attacks against government agencies are on the rise and the cost is exponential (Whitehouse, McCaul, Evans, Bhalotra, & Lewis, 2017). Maritime
operations increasing reliance on digitization, integration, automation and network-based systems have created an increasing need for cyber risk management in the shipping industry. In July 2017, IMO issued a Guideline on Maritime Cyber Risk Management advising maritime communities on maritime cyber risk management to safeguard shipping from current and emerging cyber threats and vulnerabilities (IMO, 2017b). At the VTS front, IALA recognises an increase in cyber security risks during data transfer. Cyber security precautions will remain vital. However, there are no IALA guidelines and recommendation issued advising members of the action against cyber-attacks.

VTS interaction with MASS requires a new form of digital service. The service will provide for exchange of navigational and voyage information between VTS and MASS. With more connectivity required, both VTS and MASS will be exposed to high risk of cyber-attacks. Thus, VTS needs to look into two areas of concern; threat to VTS systems and individual vessel within VTS area.

Vessel Traffic System is an important marine traffic monitoring system; it plays the centre role in communication is a rewarding target for perpetrators. Port operations can be easily affected when information exchanged between VTS and MASS is manipulated. In a more severe scenario, the safety of vessels can be threatened by falsified navigational information. For targeted attacks on single vessels, the VTS would need to monitor the infected vessel and ensure that it does not affect the safety of navigation in the VTS area. Therefore, VTS should provide adequate defence and contingency plan against being used by perpetrators to disable shipping traffic, and provide assistance to MASS, which is disabled by a cyber-attack.

6.6 Adoption of Marine Regulations

MASS will pose a great challenge to current maritime law.

First, the lack of human presence on-board will restrict its compliance to COLREGs. In particular, rule 5 of the COLREGs requires “Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate
in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision”. Unless the lookout by sight and hearing requirement can be satisfied by the use of audio-visual methods, this will restrict its compliance to COLREGs. Second, the traditional role of the shipmaster will disappear and the associated legal duties and liabilities will be dispersed to other actors (Carey, 2017).

While providing the traffic information service, VTSOs will need to be aware of the legal relationship with the master and crew. VTSOs, being part of the team will share the same objective with respect to the safe movement of vessel traffic and should provide all necessary assistance to aid the bridge team with the information required for decision making (IALA, 2016). Ultimately, the decision on the action lies with the master, who is in the best position and has knowledge about the vessel. This responsibility is stated in IMO Resolution A.857(20) as: “VTS operations do not encroach upon the master’s responsibility for safe navigation, or disturb the traditional relationship between master and pilot.”.

However, the same resolution A.857(20) also states that: “When the VTS is authorized to issue instructions to vessels, these instructions should be result-oriented only, leaving the details of execution, such as course to be steered or engine manoeuvres to be executed, to the master or pilot on board the vessel.”. With the absence of the master on the vessel, this action would presumably be executed by the SCC operator. According to MUNIN’s analysis, the legality and liability of the master will lie with the SCC operators. Hence, practically and legally, the obligations of the ship’s master will be imposed upon the SCC, and the responsibility passes on to SCC operators (Safari & Sage, 2013).

IALA VTS Guidelines and Recommendations, currently, do not stipulate the requirement for the master to be on board. This is because the existing relationship between the master and VTSOs literally exist over space. While carrying out their legal functions, there is no physical interaction required between them. The VTS obligation is to ensure timely and accurate information being delivered to appraise the
master. Therefore, it is foreseen that the current functional relationship will persist between SCC operators and VTOS.

Nonetheless, VTS and SCC must consider the potential legal issues as taking over control of MASS by VTS is necessary to prevent loss of life and protection to the environment. This could be due to communication between SCC and MASS being compromised. If yes, this would alter the traditional legal responsibility where traffic management is always the responsibility of persons on board.
7 CONCLUSION

The aim of this dissertation was to analyse future maritime transportation proposing the introduction of MASS and its interaction with conventional vessels in order to identify potential effects of MASS on VTS operations. To determine this, the researcher used gap analysis to identify areas of improvement. Factors identified in SWOT-AHP analysis on Autonomous Shipping by the Istanbul Technical University were used as guide to identify potential gaps. These factors in Weakness and Threat were further shortlisted based on their relevance to VTS operations.

The analysis shortlisted six factors from the Weakness and Threat. These factors were examined against existing IALA VTS Guidelines and Recommendations to identify areas that could affect VTS operations. Participation in pilot simulation study further ascertain human element related issues on interaction between VTS, manned ships with SCC operators. The finding sheds light to some of the challenges VTS will need to address in order to manage both, manned and unmanned ships safely.

7.1 Challenges

These challenges can be categorised into the following areas;

- Operations
- Technical
- Training
- Regulation

7.1.1 Operations

The absence of a master on board will change some of the traditional interaction with VTS. For instance, in an emergency, there will be no crews to assess the situation on board and communicate with VTS. Information will only be available through SCC operators, who have limited visual information in a form of video and other sensors.
As such, VTSOs will be limited to the information it receives when coordinating emergency services.

Another aspect of MASS affecting VTS operations is the change in method of communication with manned ships and VTS. Physical (sight and hearing) and VHF communication between MASS and manned ship will be limited. There will be no crew to use signals and symbols prescribed in the COLREGs, and signals in the International Code of Signals to make their intention and status clear.

Furthermore, SCC operators' method of communication with others will be mainly through digital format. This will heavily rely on data link and communication infrastructure available. In time, there may be limitation to communicate with VTS and manned ships effectively. Thus, to facilitate the exchange of information, the VTS would need to coordinate communication by disseminating information amongst manned and unmanned ships. The VTS will need to

From a VTS perspective direct access to control/steer a MASS seems to be an operational mode that could contribute to safety of navigation for all ships in the whole area a VTS covers. This, however, may require further studies into technical and moreover legal prerequisites.

7.1.2 Technical

Voice communication will remain a useful form of interaction between VTSOs, SCC operators, and unmanned ships. From the simulation experiments, SCC Operators felt that voice communication is essential for safe conduct of passage especially in area where there is heavy shipping traffic. Therefore, VTS need to consider means to provide and support a common platform of communication for both manned and unmanned ships within the VTS area.

The increase in the reliance of software and digital information will expose VTS operations to new challenges. The VTS would need to increase the number of ICT systems to interact with MASS. Consequently, the risk of an IT system being
compromised will be significantly higher than the current VTS system. It runs the risk of a security breach by perpetrators who may leverage off the VTS network to disable shipping traffic. Perpetrators may also hijack individual vessels to carry out attacks on port facilities.

The VTS will need a robust system and software to support the availability, reliability, and security of this communication. To sustain uninterrupted communication with MASS, the VTS will need to provide an infrastructure around the coast with sufficient bandwidth to support the connectivity and high volume of data exchange (Höyhtyä, Huusko, Kiviranta, Solberg, & Rokka, 2017).

7.1.3 Training

It is anticipated that managing MASS operations will require new VTS operational procedures and systems. Hence, VTS Authorities need to ensure adequate training for VTSOs to be familiar with the operational risks and functions of the new systems. They need to be equipped with the competency to support shipping traffic where MASS is operating. The training must familiarise VTSOs to aid MASS in difficult navigational or meteorological circumstances or in case of defects or deficiencies. They should be capable to respond to emergency situations such as distress, marine pollution and other special circumstances. Where arranged, they should co-ordinate communications with ships, allied services and other agencies. It is also anticipated that VTSOs will require a certain amount of IT knowledge to understand the underlying principles of MASS operations.

7.1.4 Regulation

Existing functional relationship between the master and VTSO literally exists over space, and this will remain the same in future interactions with unmanned ship. The role of the VTS is to deliver timely and accurate information to facilitate efficient, safe, and environmentally friendly maritime traffic movements. Therefore, it is foreseen that the current functional relationship will persist between SCC operators and VTSOs.
However, in unforeseen circumstances when communication between SCC and MASS is interrupted, in the interest of safety of life at sea and environmental protection, coastal States may require VTS to establish plans with SCC to take over control of MASS. In such circumstances, a new regulation is required to establish the legal relationship between SCC and VTS.

7.2 Benefits to VTS Operations

Lastly, apart from the researchers’ claims on the reduction of marine accidents due to human error, MASS operations will bring forth several benefits to enhance safety of navigation in the VTS area. System developers felt that information gathered by video and sensors can be transmitted directly to vessel traffic monitoring services. This will improve coastal authorities’ SA and be especially helpful in Search and Rescue operations.

Digital communication will improve efficiency and safe management of traffic. Voyage information shared with VTS and other vessels will help improve visibility of intended routes. This service will benefit ship to ship interaction, especially if an unmanned and autonomous ship is involved (Burmeister H.-C., Bruhn, Rødseth, & Porathe, 2014). Availability of navigational information digitally will reduce the potential of miscommunication due to language barriers.
8 RECOMMENDATIONS

Based on the findings of the research, the following recommendations are proposed to the VTS Authority and IALA for consideration.

8.1 Recommendations to the VTS Authority;

- Conduct Risk Analysis (IALA, 2013) to identify potential hazards. Thereafter, develop risk control measures for safe management of MASS operating among other shipping traffic in the VTS area for routine and emergency cases.
- Develop a proactive emergency response which includes a communication plan with SCC and emergency services.
- Consider the need for SCC to locate in the VTS centre to facilitate efficient management and communication during an incident.
- Review legal liability of the VTSO’s role in emergency response.
- Provide the communication infrastructure necessary to support the high volume of data transfer between the VTS and MASS. Navigational information that is crucial must be available in digital form to support MASS communication.
- Secure IT infrastructure against cyber-attacks, addressing systems, software, procedures and human factors.
- Perform training need assessment to evaluate the necessary skills and knowledge for VTSOs to manage future shipping traffic. Develop Adaptation Training (IALA, 2017c) to ensure VTSOs skills are adapted to new changes.
8.2 Recommendations to IALA;

- Conduct Formal Safety Assessment to study the impact of MASS to VTS operations and develop a high level strategy plan to improve the provision of VTS to MASS.
- Develop harmonised navigational information data exchange between manned ships, unmanned ships and VTS.
- Develop guidelines on minimum standard of the IT system required to provide uninterrupted and secured communication.
REFERENCES


