YRKESHÖGSKOLAN NOVIA

Autonomous Ships and Salvage

Risks, Challenges and Opportunities related to salvaging an autonomous vessel

Richard Robertson

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Author: Richard Robertson
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Supervisor: Dr Thomas Finne

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Abstract

The advent of autonomous vessels marks a significant transformation in maritime operations, promising enhanced efficiency, safety, and cost-effectiveness. However, the introduction of Maritime Autonomous Surface Ships (MASS) into the marine environment also presents unique risks and challenges, particularly when it comes to the salvage of these vessels following incidents or failures. Using qualitative research, this thesis aimed to provide a brief historical overview of marine salvage, then explores the multifaceted aspects to consider when salvaging autonomous vessels, while examining the technological, operational, and environmental dimensions. As a result, this thesis highlights the opportunities that arise from developing new methodologies and technologies to support effective salvage operations.

Language: English
Key Words: autonomous, ships, salvage, MASS

"I cannot imagine any condition which would cause this ship to founder. I cannot conceive of any vital disaster happening to this vessel. Modern shipbuilding has gone beyond that."

Capt. Edward J. Smith - Titanic, 1912

Abbreviations

AI	Artificial Intelligence
IMO	International Maritime Organization
MASS	Maritime Autonomous Surface Ship
COLREGS	Convention on the International Regulations for Preventing Collisions at Sea
RCC	Remote Control Centre
WIG	Wing in Ground
AMEC	Autonomous Engine Monitoring and Control System
GMDSS	Global Maritime Distress and Safety System
IBS	Integrated Bridge Systems
Satcomms	Satellite Communication
GEO	Geostationary
HEO	Highly Elliptical Orbit
MEO	Medium Earth Orbit
LEO	Low Earth Orbit
SAR	Search and Rescue
IT	Information Technology
C2	Command and Control
ASM	Advanced Sensor Module
IBS	Integrated Bridge System
EAS	Engine/Automation Systems
VTMIS	Vessel Traffic Management Information System

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1 Introduction

At the end of the 1800’s, the renowned inventor Nikola Tesla filed a patent application (no. 613,809, dated November 8, 1898, with an application date of July 1, 1898, serial number 684,934) titled “Method of and Apparatus for Controlling Mechanism of Moving Vessel or Vehicles.” In this application, he emphasized a key feature of his invention: the absence of cables or mechanical connections. This groundbreaking innovation marked the creation of the first radio-controlled craft - a three-foot long boat – the ’*telautomaton*’.

Since Mr. Tesla’s telautomaton, technological advances in remote control and automation have been exponential in recent years. The advent of autonomous technologies has extended its reach beyond land and air, making significant strides in the maritime industry. Autonomous ships operating in both inland waterways and deep ocean navigation are no longer a farfetched idea and have become a reality, which is expected to further develop and grow in years to come. One crucial aspect for autonomous ships is their ability to deal with unexpected situations, including accidents, groundings, flooding, collisions, cyber-attacks or equipment failures. In such scenarios, salvage operations play a vital role in responding to an incident on board, stabilizing the situation and bringing the ship to safety.

Salvors have supported the maritime industry transition from sail to steam, steam to diesel, flags to radio and radio to satellite communications. These much-needed services will continue to be supported by salvors regardless of the technological context (Coll, 2018). This research aims to provide a comprehensive understanding of the salvage process, highlighting the risks and challenges associated to responding to an autonomous vessel requiring salvage assistance. After highlighting some of the different possible salvage situations an autonomous ship may encounter and the challenges associated with them, this research study reviews these situations to establish how autonomous ships could better prepare themselves for such situations.

1.1 What is a Shipping Emergency?

A shipping emergency means a major incident on board a ship that has the potential to put at risk the safety of personnel, the ship, the environment or cargo (Oil Companies International Marine Forum [OCIMF], 2020).

When an incident on board a vessel escalates to a potential emergency situation, a number of factors need to be taken into account, such as what are the immediate actions that need to be taken on board and in what order do they need to be carried out to deliver the best results; is external assistance required and to what extent; what types of external assistance are readily available; what are the risks of the situation becoming worse; and what is the worse-case scenario. (OCIMF, 2020)

During the operation of a ship, including autonomous vessels, it is inevitable that incidents will occur. These incidents can range from minor issues that are quickly resolved to major incidents that require the ship's captain, manager, operator, owner, or insurer to seek additional assistance. Such external support, in the form of marine salvage assistance, is often crucial to addressing the issue and stabilizing the situation on board.

1.2 Marine Salvage

It has been estimated that there have been as many as three hundred thousand ships lost per century from the moment man took to traversing the open waters in man-made vessels, harnessing first the waves, and later on the wind (Forrest, 2003). With reference to the large amount shipping incidents over the years, marine salvage dates back to the start of maritime trade with the Rhodian Code (circa 500 B.C to 300 B.C) which covered maritime matters in Greece and the surrounding Mediterranean. This code granted voluntary salvors a reward for their services (Ashburner, 1909).

Salvage in its essence refers to the process of rescuing ships in distress, preventing their grounding, sinking or flooding, and mitigating the associated risks to the environment, maritime traffic, and human life (Maritime Page, 2023). Marine Salvage is defined by the International Maritime Organization (IMO) as “a voluntary response to a maritime peril by other than the ship’s crew and from which the ship or property could not have been saved without the effort of the salvor” (International Maritime Organization [IMO], 1989). The Salvage Convention under Article 1(a), goes on to say that a salvage operation entails any act or activity undertaken to assist a vessel or any other property in danger in navigable waters or in any other waters whatsoever (IMO, 1989).

According to the International Salvage Union (International Salvage Union [ISU], 2024), marine salvage can be divided into three categories, which are as follows:

- Emergency Response – “Dry Salvage”
- Wreck Removal – “Wet Salvage”
- Environmental Care – “Special Services and Projects”

Within these categories of salvage, various types of salvage exist. It is crucial to understand that a salvage operation does not necessarily remain confined to a single category. A salvage operation may begin in one category, span across two, or even encompass all three categories simultaneously. For instance, a salvage operation may begin as an emergency response (Dry Salvage) to a fire on board the vessel. Due to the vessel's condition or external circumstances, the vessel could take on water and sink, becoming a navigational hazard that necessitates its removal. At this stage, the salvage operation transitions to a wreck removal (Wet Salvage). Once the wreck is cleared, the area or seabed where the vessel rested might need restoration. Consequently, the salvage operation progresses to Environmental Restoration (Special Services and Projects) to rehabilitate the damaged area caused by the sunken vessel.

The following section further elaborates on the different types of salvage within the salvage categories.

1.2.1 Emergency Response – “Dry Salvage”

Emergency response in terms of “Dry Salvage” refers to the immediate actions taken to save a vessel and its cargo that are in distress, in danger, or at risk. The main objectives of an emergency response salvage are to ensure the safety of personnel, prevent further damage, and protect the environment.

Typical “Dry Salvage” scenarios include several critical and often perilous events. Grounding refers to a situation where a ship or vessel runs aground, meaning it makes unintended contact with the seabed, shore, or underwater objects like rocks or coral reefs. This can occur due to navigational errors, mechanical failures, or environmental conditions such as low tides. Grounding can cause significant damage to the hull of the vessel, potentially leading to leaks or breaches that may result in flooding and environmental contamination from spills. Collisions, involve forceful contact between two ships or between a ship and a floating object. This can result from navigational errors, poor visibility, mechanical failures, or human error. Collisions can cause severe damage to the involved vessels, injuries to crew, and environmental pollution if hazardous materials are spilled. Fire and explosion scenarios on a ship involves the outbreak of uncontrolled flames or an explosive reaction on board. Fires can originate from various sources, such as volatile substances, gas leaks, electrical faults, fuel leaks, machinery fault, cargo combustibility, or human error. Both fire and explosion pose significant threats to the safety of the crew, the integrity of the vessel, and the environment, potentially leading to catastrophic consequences including the loss of the ship. Listing describes a situation where a ship tilts or leans to one side, often due to uneven weight distribution, flooding, or damage to the hull. If the list becomes severe, it can lead to capsizing, where the vessel overturns completely. Mechanical and structural failure represent a broad category of issues, where key systems or components of a ship malfunction or break down. Mechanical failures might include problems with engines, steering, or other essential machinery, often resulting from wear and tear, poor maintenance, or manufacturing defects. Structural failures involve the integrity of the ship's physical structure, such as the hull, bulkheads, or decks, which can be compromised due to age, corrosion, damage from external impacts, or design flaws. Both types of failures can incapacitate a vessel, leading to loss of control, navigation issues, or even catastrophic events like sinking. Lastly, remote assistance involves the support and services provided remotely by a salvor to aid or guide a vessel or its crew during a salvage situation. This guidance can cover emergency procedures, stabilization tactics, and initial actions a crew or vessel carryout to prevent the unfavorable situation getting worse. For autonomous vessels, this form of salvage assistance has the potential to become more prevalent and is elaborated further in this thesis when referring to a cyber-attack on a Maritime Autonomous Surface Ships (MASS). This form of salvage assistance provided to the MASS is not necessarily a tug or team of salvors boarding the vessel, but a cybersecurity specialist whose primary role involves actively defending against cyber-attacks and responding to systems that have been hacked.

1.2.2 Wreck Removal – “Wet Salvage”

Wreck removal, also referred to as “Wet Salvage”, refers to the process of locating, assessing, and removing a shipwreck, vessel, or an object from its resting place in the water. This process is essential for ensuring safe navigation, protecting the marine environment, and complying with legal and regulatory requirements. Wreck removal can occur in shallow or deep water. Shallow Water Wreck Removal involves the extraction of shipwrecks located in relatively shallow parts of the ocean, seas, rivers, or lakes. These areas are typically more accessible for divers and salvage equipment. However, shallow water wrecks can pose significant hazards to navigation, particularly in busy shipping lanes or near ports. Deep Water Wreck Removal on the other hand deals with wrecks located at significant depths, often requiring specialized equipment and techniques due to the challenges posed by high pressure at those depths, low temperatures, and limited visibility.

"Wet Salvage" is not necessarily limited to wreck removals. It includes vessel disposal, which could be intentional like scuttling, scrapping or recycling of the vessel. Scuttling is the intentional sinking of a ship by allowing water to enter the hull. This can be done for various reasons, such as creating artificial reefs, or a vessel is not safe or in an acceptable state to be towed into a port or safe area. Further reasons for scuttling could be that the vessel is used in a naval exercise providing a target for military training. Scrapping refers to the dismantling of a ship for its raw materials and reusable parts. This is typically done in shipbreaking yards. Recycling, in the context of vessel disposal, focuses on the sustainable and environmentally responsible reuse of materials and components from decommissioned ships.

1.2.3 Environmental Care – "Special Services and Projects"

Environmental salvage refers to specialized efforts and operations undertaken to protect and restore the marine environment, either as standalone projects or during and after salvage operations. These services and projects are essential for mitigating environmental impacts caused by maritime incidents or potential incidents. The main objectives are to prevent pollution, protect marine life, and restore affected ecosystems.

1.3 Maritime Autonomous Surface Ships (MASS)

MASS has been defined by the IMO as "ships which, to a varying degree, can operate independently of human interaction" (IMO, 2018). MASS in essence are highly automated ships, using state-of-art Information Technology (IT), data analysis techniques, onshore monitoring and control bases connected through telecommunications to operate. They automatically carry out part of or all the on board tasks associated with ship operations, including observing its surroundings, monitoring equipment status, manoeuvring, operating engine control, performing cargo management and loading, docking and undocking. (Wariishi, 2019)

The IMO has determined four degrees of MASS (IMO, 2021):

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

- Degree two: Remotely controlled ship with seafarers on board. The ship is controlled and operated from another location, but seafarers are on board.

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

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

Most MASS will be equipped with communication systems that connect them to a home base, enabling a Remote Control Centre (RCC) to receive status updates and send operational instructions. This Command and Control (C2) communication link is essential for the RCC to monitor the vessel's status remotely and to intervene by overriding autonomous functions during emergencies or critical failures. Additionally, some vessels may be able to transmit telemetry or imagery data back to the RCC. They will also have internet access through satellite connectivity, to gather open-source information like global marine traffic and climate forecasts. The C2 and data links will utilize a mix of technologies, such as cellular, satellite, VHF, UHF, and Wi-Fi, depending on the required communication range and data transfer speeds. An overview of the operational concepts of MASS can be seen in Figure 1 below.

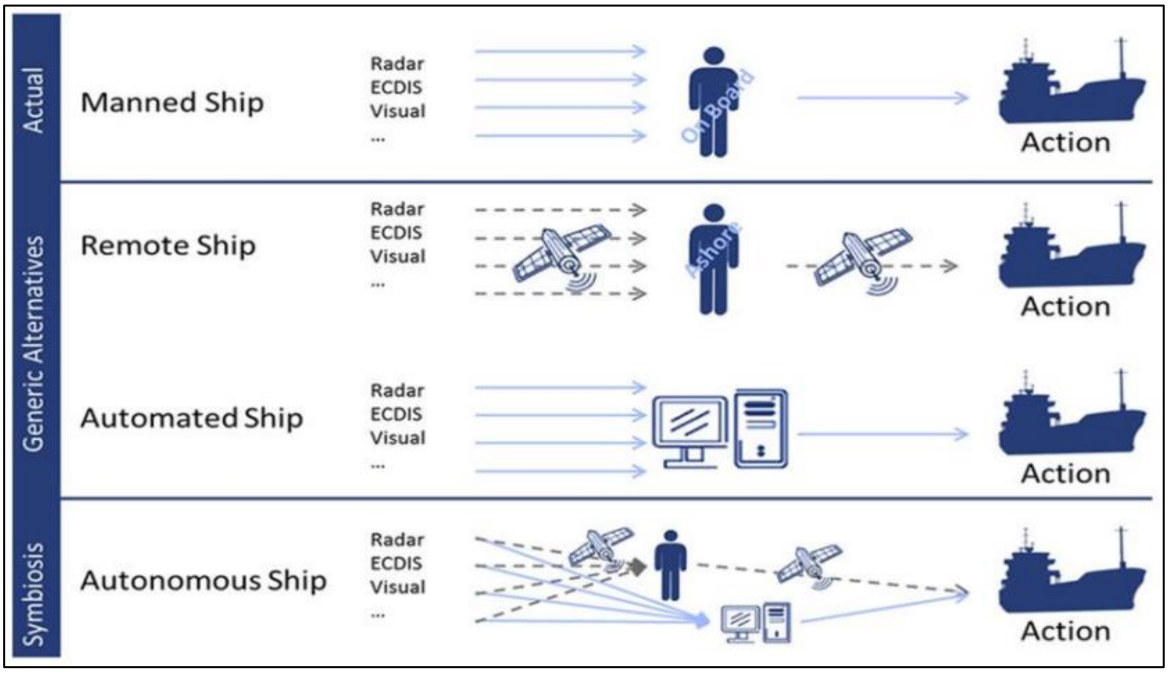

Figure 1: Illustration Supporting IMO's Operational Concept of MASS (MUNIN, 2016)

Given the vast amounts of systems and technologies expected on board a MASS, it is important to have an understanding of the technological architecture on board to help identify and discuss potential risks, challenges and mitigating measures. The project 'Maritime Unmanned Navigation through Intelligence in Networks' (MUNIN, 2016), a collaborative research project by eight organisations from 2012 to 2015 co-funded by the European Commission, identified the main modules and components of an autonomous ship. These modules included Advanced Sensor Modules (ASM), which comprises of radar, video and other systems for lookout, object detection and generally sensing the ship's environment. Integrated Bridge Systems (IBS), which comprises of all bridge systems and equipment related to the navigation of the ship. The name 'bridge' implies that its basic functionality is somehow equivalent to a physical bridge found on ships today. Engine/Automation Systems (EAS), that comprise of all systems related to power generation and propulsion. The MUNIN project also assumed that it would also include automation related to safety systems, life support, ballast and cargo control and so forth. An Autonomous Ship Controller (ASC) is the additional control and monitors functions that enable autonomous operation. It includes an 'Autonomous Engine Monitoring and Control' (AEMC) function and the 'Autonomous Navigation System' (ANS) modules. It also includes communication management functions for all communication between the vessel and the

RCC through the Communications Controller. The Dedicated Line-of-Sight Communication Systems communicates with other ships and shore facilities including Vessel Traffic Management Information System (VTMIS), and Maritime Rescue Coordination Centres (MRCC). It comprises AIS, VHF Data Exchange System (VDES), which is the 2nd generation of AIS using satellite communications and Global Maritime Distress and Safety System (GMDSS), the mandatory emergency signal communication system. The Rendezvous Control Unit is a system that allows an On board Control Team to take control of the ship temporarily or an Emergency Control Team to recover the vessel during a breakdown. The RCC contains all onshore functions to handle an autonomous ship. It also includes remote bridge and engine control modules that can be used to directly control the ship. Initial voyage planning would be performed from the RCC.

Wang, Xiao and Chen, in their article Survey of Technologies for Unmanned Merchant Ships (2020) identified a list of core technologies required for a MASS, as shown in Table 1.

Table 1. Core Technologies for MASS

Core Technologies	Description
Gyroscope	Senses the ship’s movements, indicating average and peak movement around three axes, and also vibrations.
Intelligent Awareness	Relies on advanced sensors on board that monitor for hazard detection and avoidance and situational awareness, such as automated surveillance cameras and accelerator sensors.
Sensor Fusion	Monitors, evaluates and processes individual sensor data to improve sensors'output.
Route Planning	Global route planning relies on static obstacle information of the sea area. Local route planning is based on sensor information to determine the optimal route.
Collision Avoidance	Includes obstacle detection, tracking and motion estimation to ensure safenavigation.
Communications	Includes LF, HF, VHF/UHF, satellite, Celular3G/4G/5G.
Autonomous Navigation	Different technologies such as satellite navigation (based on GNSS and Differential GNSS), dead reckoning (a method to obtain the track and position of a vessel based on speed, heading, water current, etc.), inertial system (a way to determine speed and position using accelerometers) and multi-sensor navigation (using radar information in addition to other sensor information) maybe employed for autonomous navigation.
Energy Control	Uses energy control algorithms to optimize efficiency.
Status Monitoring System	Monitors the status of a crewless ship.
Fault Diagnosis System	Diagnoses faults quickly and effectively to prevent and reduce accidents.
Cargo Supervision	Identifies the positioning and management of the cargo. Cargo can be a sensor,a weapon system, people, containers, etc.

System	
Emergency Response System	Transmits the situation of a ship in real-time when in danger for response action from the SCC.
LiDAR System	Detects targets by emitting laser waves and receiving the reflected echo forcollision avoidance, location and navigation.
Radar System	Detects targets by emitting electromagnetic waves and receiving the reflectedecho for collision avoidance, location and navigation.
Dynamic Positioning	Provides data to maintain the position of the vessel using the propellers withoutanchoring.
Strain Gauge	Measures and monitors the strain of a ship and equipment.
ECDIS	Provides digital layered charts fused with ship positions to assist decision-making for navigation.
Iceberg Tracking	Icebergs can be detected by radar and sonar.
AIS Transponder	Gives situational awareness of other vessels in the vicinity, but it is a collaborative system.
Remote Human Vision	Monitors and intervenes from the SCC in crewless ships.
AI/ML	Path tracking and planning using a set of sensor inputs.
Edge Computing	Autonomous ships need to perform a complex set of calculations on a real-timebasis with low latency.

2 Research Study

The hypothesis explored in this research is that there are multiple risks associated with other vessels and/or salvors responding to an autonomous ship in need of salvage assistance, and to identify what those risks are. In pinpointing these risks, it becomes clear that salvors and other responders will inevitably face challenges in providing an effective response. This raises the critical question: What measures can be taken to mitigate these risks and help responders to an autonomous vessel in distress overcome the anticipated challenges?

2.1 Research Aim

The aim of this research is to determine whether salvage operations on MASS will be 'business as usual' for salvors or whether the unique risks and challenges of assisting an autonomous vessel necessitate proactive collaboration among salvors, MASS operators, designers, and owners. This should provide the opportunity in this developing sector of the maritime industry to engage with each other from the design phase all the way through to the operation of the MASS. The goal would be to ensure that all parties understand what to expect in the event of an incident and know the necessary steps to prevent or mitigate such events on board a MASS.

2.2 Research Questions

This research centres around whether salvage operations on an autonomous vessel will be any different to what traditional salvage operations are perceived to entail. In doing so, this research highlights the expected risks salvors may have when responding to an autonomous vessel that is in peril, including the challenges they may face in their response to salvage the vessel. In highlighting the potential risks and challenges, this research also brings forward opportunities that could help reduce the risks and challenges salvors may face when responding to an autonomous vessel.

To meet the aim of the research, the following primary question is posed:

- What are the risks, challenges and opportunities related to salvaging an autonomous vessel?

In support of the research, two sub-questions were put forward:

- Are professional salvage companies ready, skilled, and equipped to respond to an autonomous ship in distress or will traditional salvage techniques and methods see salvage companies through the dawn of autonomous ships and into the future?

- Are autonomous ship designers, developers and operators considering and implementing designs, procedures and systems on board to facilitate a salvage response to the vessel when it is in distress?

2.3 Scope and Limitations

To date there have been no reported contracted salvage cases of operational autonomous vessels requiring salvage assistance. This limits practical cases of autonomous ship salvage to investigate and review. There have, however, been cases of military autonomous vessels washing up on the shore (The Warzone, 2022) and MASS requiring human intervention/assistance during trial operations (Maritime Executive, 2021). Taking into account the latter, the risks and challenges of autonomous ship salvage in this thesis have been predominantly based on previous experiences of conventional salvage operations and hypothetical scenarios retrieved from the extensive research into this topic.

For the purpose of this thesis, considering the various categories and types of marine salvage, the research focuses specifically on emergency response (Dry Salvage) of autonomous vessels.

Taking into account the four degrees of MASS, the primary focus of this research is relevant to unmanned vessels: Degree Three and Degree Four MASS.

The term ‘vessel’ is a relatively broad term, defined as “every description of water craft, including non-displacement craft, WIG craft and seaplanes, used or capable of being used as a means of transportation on water” (IMO, 1972) and not restricted to size. The focus of this research is on larger (>24m LOA) commercially operated autonomously operated vessels.

Researching the regulations and legalities surrounding autonomous ships and salvage has been a topic of debate among maritime lawyers, academics, government bodies, and international organizations for some time. It is impossible to study MASS in the context of salvage operations without addressing relevant legalities and regulations within maritime law. However, this thesis focuses on the practical aspects of salvage operations involving autonomous vessels in need of assistance, rather than providing a legal analysis or theoretical exploration of salvage law and MASS.

2.4 Research Method

Research methodology is a practical process used in conducting research. According to Jansen (Jansen, 2020), a research methodology is a systematic approach a researcher deploys to obtain valid and credible results that address the research's purpose. It elucidates the motives and research techniques utilized.

The research methodology adopted for this thesis is qualitative. Qualitative research involves collecting and analyzing non-numerical data (e.g., text, video, or audio) to understand opinions, concepts, events, and experiences. It receives information on the participant's views and opinions of their reality. It enables the researcher to gather in-depth insights into a problem or generate new ideas for research, thus creating an overall understanding of the quality, characteristics, and meanings of the object or topic of research rather than brief and superficial knowledge. (Bhandari, 2020).

An advantage of the qualitative method according to Rahman (2016) is that it produces detailed descriptions of participants' opinions, experiences, and feelings. Another advantage of the chosen qualitative method was that it was inexpensive and still received the required outcome. However, a disadvantage of this method is the generalizability of the whole population given the small sample size and subjectiveness of participants (Bryman, 2016).

2.5 Method of Data Collection

Taking into consideration the research questions, the very few autonomous surface ships being in operation, let alone reported salvage assistance cases of these vessels, there is minimal to no analytical data to review and research to achieve the aim of this thesis and to answer the research questions. To address this, select, experienced individuals and expert opinions were then sought via a questionnaire, which formed the basis of the qualitative investigation.

2.6 Sampling

Purposive sampling was employed to narrow the participant pool to those within the research focus area. Purposive sampling, also known as judgmental, selective, or subjective sampling, is a form of non-probability sampling in which researchers rely on their own judgment when choosing members of the population to participate in their surveys (Alchemer, 2024). The convenient and snowball sampling techniques were also used to gather responses. The convenient sampling technique drew from the researcher’s network of contacts in the maritime industry. As stated by Sahay (Sahay, 2016), the convenient sampling technique allows the researcher to enjoy a certain amount of flexibility, as the researcher only administers the instrument to respondents who stated they are interested in the study. For snowball sampling, selected participants shared the questionnaire with their colleagues or network contacts who met the sample criteria and had an interest in the research.

2.7 Research Approach

An inductive research methodology was chosen for this thesis. In the inductive technique, the researcher progresses from research questions through analysis to a hypothesis. It operates from the bottom up, utilizing the participants' replies to establish and develop a theory that connects the study issues (Soiferman, 2010). The choice to use the inductive approach stems from its focus on objectively examining diverse viewpoints, in contrast to the deductive method, which relies on subjectively evaluating perspectives to support predetermined conclusions.

3 Literature Review

Before drafting the questionnaire, a comprehensive literature review was conducted to identify what the existing knowledge was related to the research area. The literature review served as the initial step in formulating the questions by providing insight into identified risks associated with autonomous vessels during a salvage operation, challenges that these vessels may pose when in an emergency situation and how these risks and challenges could be mitigated.

The literature review was based on the inclusion/exclusion criteria defined in Table 2.

Table 2. Inclusion and Exclusion Criteria

	Inclusion criteria	Exclusion criteria
1.	Published in or after 2015	Published prior to 2015
2.	Published in English	Published in a language other than English
3.	Article published in a peer-reviewed journal	Article not published in a peer-reviewed journal
4.	Full text copy of article available	Full text copy of article not available
5.	Article focuses on MASS and challenges related to their safety or risks	Article does not focus on MASS and challenges related to their safety or risks
6.	Search terms were used in the setting/for the meaning they were intended	Search terms were used in other setting/for other meanings
7.	Non-duplicate study	Duplicate study

A number of studies and risk assessments have been done on the potential risks autonomous ships may encounter during operation. These reviews and studies are contained predominantly in journal articles (Xiang-Yu, Zheng-Jiang, Feng-Wu, Zhao-Lin, & Ren-Da, 2020), opinion pieces (Lindborg, 2021), conferences (European Maritime Safety Agency, 2022), papers (Blindheim, Gros, & Johansen, 2020) and online open resources (Chat GPT, 2024). While considerable literature and research have focused on the risks associated with operating autonomous ships, there has been minimal research on the practical aspects of responding to an autonomous ship in distress, stabilizing the situation, and subsequently bringing the vessel to a safe location. Taking this into consideration, the literature review was undertaken to understand the current state of knowledge on MASS and salvage related activities.

4 Questionnaire

A questionnaire method with a limited but diverse group of participants who had a profile of experienced maritime professionals having worked in the maritime industry, both at sea and/or ashore, were selected for the questionnaire. The participants were not provided with direct MASS definitions before receiving the questionnaire. Instead, the research relied on them being aware of MASS in the industry and what it meant to them. This was a deliberate action to offset the potential research bias that would be incurred by supplying information from the research.

A drawback of conducting a questionnaire survey with a smaller group, is that the feedback received would be limited to that group. However, the benefit of getting limited feedback from a small group of qualified participants against a more significant number of anonymous online survey responses from unknown or unvalidated persons would provide a suitable compromise to answer research questions with accuracy.

The literature review assisted in identifying prominent themes, theoretical frameworks, and gaps in the current research landscape. These findings guided the formulation of the questionnaire. The questions aim was to answer the research questions of this thesis.

To minimize the potential for research bias, the researcher maintained a critical approach and an awareness of potential research bias based on their current and previous professional roles.

All questionnaires were shared via email in a Microsoft word document. This increased the opportunity to send the questionnaire to participants from all over the globe and allow the candidates response to be flexible in timing to accommodate busy work schedules. One week was given to complete the questionnaire. Participants provided consent to their answers to the questionnaire being used as research in this thesis. It was made clear to all participants that the questionnaire did not require them to deliver confidential information and that their identities were to be kept confidential.

5 MASS Salvage Operation – Risks and Challenges

Salvage operations on autonomous vessels are expected to involve unique risks and challenges compared to traditional manned vessels. These risks can be broadly categorized into technical, operational and legal aspects. This section will elaborate further on these risk categories and challenges they have.

5.1 Technical Risks

According to the National Aeronautics and Space Administration (NASA, 2023) "a technical risk is the risk associated with the evolution of the design and the production of the system of interest affecting the level of performance necessary to meet the stakeholder expectations and technical requirements". On board a MASS there are a number of technical risks that could affect a salvage operation. In this section the perceived main technical risks are identified and assessed.

5.1.1 Sensors

For a ship to be navigated safely, any element that can affect its operational safety must be detected in a timely manner such that it can be acted upon. These elements include geography, bathymetry, fixed objects, floating objects, weather conditions and conditions of the ship which may potentially affect its maneuverability. On conventional ships, such detections are carried out by a combination of available information, sensors and crew. For an autonomous vessel, pending their degree of autonomy, the sensors will need to supplement and/or replace on board crew, increasing the reliance on sensors.

Autonomous ships heavily depend on their sensor systems for safe and efficient operation (Widyotriatmo & Hasan, 2024). Failure in the sensory system of a MASS would lead to it becoming blind, inevitably leading to it being unable to perform safely and efficiently (Wróbel, Montewka, & Kujala, 2018). Literature generally distinguishes between sensors for sensing the environment outside the vessel and sensors that measure the current state of the vessel (Dreyer & Oltedal, 2019). In terms of a salvage operation, similar to the Remote Control Centre (RCC) for a MASS, the sensors on board provide salvors with valuable information on where the vessel is, what state the vessel is in, where any concerns/alarms are on board and to what extent/severity the damage or issue is.

There are a number of potential sensor failures that may affect a salvage operation, which are in this section, elaborating the risks associated to those failures or inefficiencies.

The position of the vessel is critical for safe operations. Global Navigation Satellite System (GNSS) systems are relied upon by vessels for navigation by providing of precise position fixes worldwide. GNSS provides real-time position information on board ships to an accuracy of meters (ITU, 2017). It is expected that the GNSS receiver will be the primary source of position information for the autonomous ship. It is a very reliable and accurate positioning system, however, the problem of threats to its correct operation is currently being raised (see Figure 2). The most common threat is currently an intentional jamming interference and false signals sent intentionally with the intention of misleading the receiver (Felski & Zwolak, 2020). Loss of or inaccurate positioning data will delay or hinder any salvage team or vessel responding to the MASS requiring salvage assistance. Without accurate and continuous position reporting of the vessel, responders would have to rely on alternative means to locate the vessel, such as - dead reckoning plots from its last known position, if the MASS was still underway and making way; drift prediction plots if the MASS was drifting; visual sighting reports from passing ships; coastal radars; reconnaissance aircraft; or satellite imagery. The alternative means to determining the vessels position, in the absence of a person on board who could physically plot the vessels positions and relay the position to the RCC via satellite phone or VHF, all take time and may not be very accurate. A functioning and reliable positioning system/sensor is not only required to relay the MASS's position, but also its heading and speed, if underway, which are necessary to keep the vessel stable on the most suitable heading in adverse weather or when a salvage team are required to board the vessel. GNSS's have a number of variabilities, which are highlighted in Figure 2.

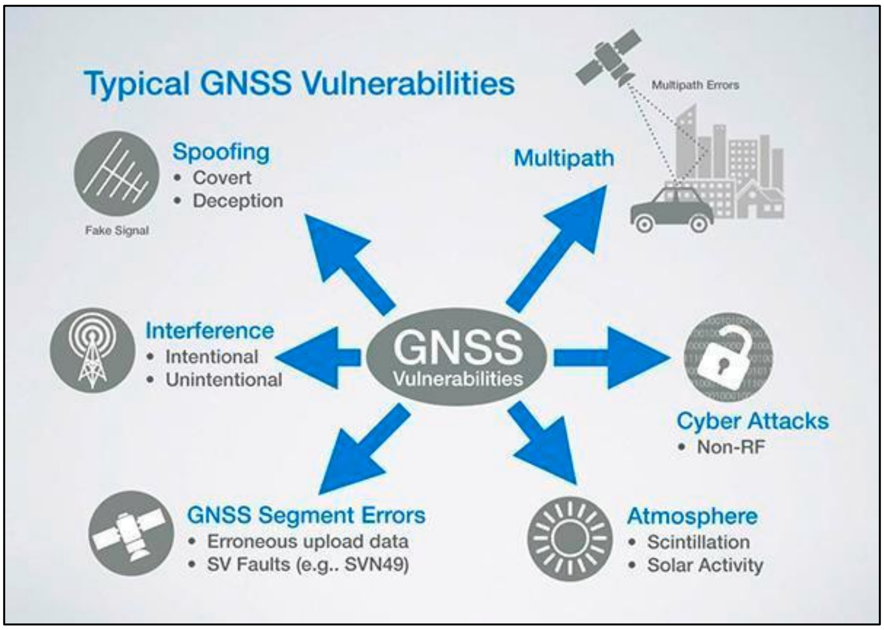

Figure 2: Typical GNSS vulnerabilities (Buesnel, Pottle, Holbrow, & Crampton, 2016)

Weather routing for both conventional vessels and MASS is an integral part of any vessels planned voyage (IMO, 1999). Weather services have been provided on the oceans for years, tasked to recommend optimal weather routes ensuring safe navigation within optimized period of time. Shipowners pay for the access to this information, and ships usually get specific recommendations, which may be taken into account by the captain fully, partially or ignored. For MASS, the role of such services will undoubtedly be increased. The inaccurate or missing data on weather conditions (meteorological and oceanographic) can lead to poor decision-making, increasing the risk of safety to a MASS and its cargo. In the case of unmanned vessels, a recommended ocean route will change its status to the mandatory route, as it seems that a system operator will not be able to ignore such recommendations. (Pietrzykowski & Hajduk, 2019). This planning aims to avoid severe weather, minimize fuel consumption, and ensure timely arrival. Weather routing is done before the vessel commences its planned voyage, but needs to be updated regularly, taking in account weather forecasts and actual weather conditions observed by the vessel enroute. Environmental sensors on board a MASS will be essential in providing up to date and accurate weather data. If no or inaccurate environmental conditions are being recorded and relayed into the MASS's navigational system or to the RCC ashore, it risks putting the vessel in an unsafe or unfavorable position/heading relative to the wind, waves and current. This will then create an unstable or unsafe platform for salvors to board the vessel and/or exacerbate the existing issue on board the vessel.

Automated engineering systems perform the control and operation of the engines, generators, power distribution, drive train, fuel and lubricating systems, steering gear, and the many other system components and machinery of an operational ship. This is accomplished through continuous live monitoring of many thousands of data points within these systems that reflect pressure, temperature, flow, viscosity, power, torque, emissions, vibration and other factors, often indicated as functions of voltage, current and resistance (Wright, 2020). The Autonomous Engine Monitoring and Control System (AEMC) is the autonomous controller for the engine room. It monitors and controls all engine room components and works as a transceiver for the RCC. The most important features of the AEMC are autonomous control of the engine room and emergency handling. Both functionalities require direct access to the ships automation system and additional sensors e.g. Infra-Red cameras, water ingress detection, gas detection and fire detection. Emergency handling contains detection of a failure through monitoring of values. Furthermore, it contains the start of countermeasures to avoid damages to ship components. (MUNIN, 2016). Like the bridge of a MASS, the engine room on board is intended to be an unmanned space, relying on sensors within the machinery spaces and on the machines themselves, to monitor the functioning and performance of the machinery – ref. Figure 3. Failure or inaccurate sensors monitoring the engine, fuel levels, or other critical machinery can lead to unexpected breakdowns, reducing the operational efficiency and potentially causing the vessel to become immobile. Carrying out a salvage operation on board an immobile vessel is no new activity or task for salvors. The issue of an immobile MASS, fully reliant on sensors to report on and activate critical machinery may prove to be difficult in a salvage situation. During a normal salvage operation, once a salvage team have boarded an immobile/dead ship, one of the essential tasks for the salvage engineer is to reinstate the engine room or reactivate power and systems on board. On board a MASS, this would require the salvage engineer to have access to the vessels system(s) to reinstate dysfunctional machinery or have to override the systems to manually reactivate the machinery. To achieve the latter, the salvage engineer will invariably have to have the relevant training on how to gain access to the vessels machinery systems as well as have the necessary user rights to gain access to the machinery or override it and manually operate the machinery.

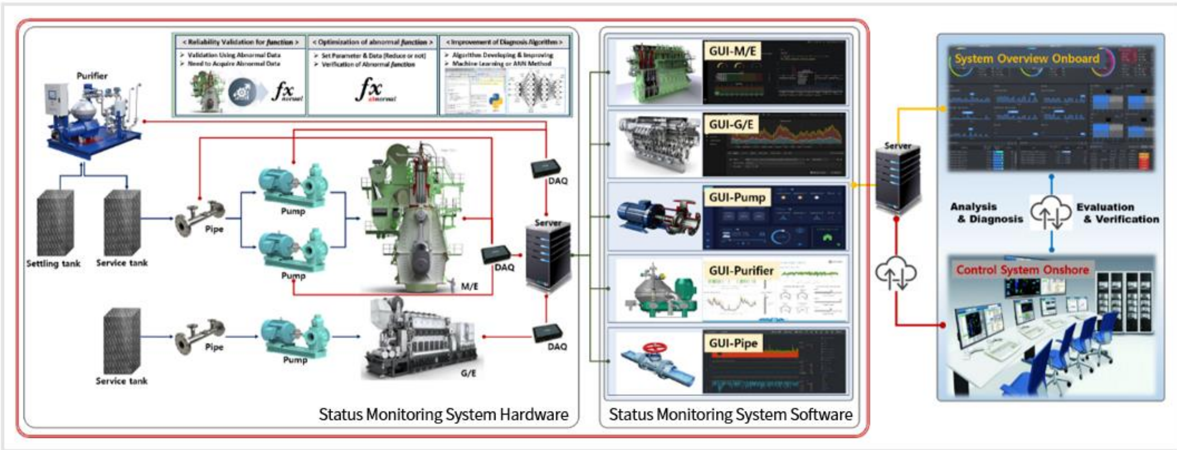

Figure 3: Technical Composition Diagram of machinery sensors and monitoring on board a MASS (Korea Autonomous Surface Ship Project, 2020)

An integral part of assessing a vessels condition during normal and salvage operations, is knowing what and how much is contained in the vessels tank spaces. A ship is fitted with different types of automatic and manual sounding measuring systems/sensors wherein the level of the liquid in the tank can be checked remotely or locally. The types of measuring systems can be manual soundings, electronic sounding gauges, electrically powered servo-operated gauges, bubbler gauges, differential pressure gauges, ultrasonic gauges, and mechanical sounding gauges (Wankhede, 2021). The general standard on board ships and depending on company policy, is to utilize the remote sensors on board to sound tank spaces and regularly (if not always) confirm the figures given by the sensor with manual soundings. The reason for this is that remote sounding sensors are susceptible to errors if not calibrated or maintained regularly and more importantly, they are reliant on a source of power to operate. During a salvage operation the preferred means of reporting on the status of a tank space is by means of a manual sounding, either taken by the ship's crew or by the salvage team on board. The risk of not having regular accurate soundings, or the ability to manually take soundings, during an emergency situation on board or reports on whether the tank space is "breathing" through the sounding pipe (the telltale signs of a tank space being breached) will potentially affect the accurate condition assessment of the vessels tank status. This potentially has an effect not only on the stability of the vessel, but the environment as well, if the damage is to a tank containing hydrocarbons or other marine pollutants.

5.1.2 Communications

A critical component of any unmanned and autonomous ship is the communication systems supporting efficient and safe operations (Höyhtyä, Huusko, Kiviranta, Solberg, & Rokka, 2017). Autonomous vessels rely heavily on robust communication systems for navigation and control through modern integrated bridge systems (IBS). The communication architecture of a MASS must be safe and reliable and is generally distinguished between two different types of communication – Ship-to-Ship and Ship-to-Shore (Dreyer & Oltedal, 2019). To establish trust and avoid dangerous situations, an autonomous ship needs to communicate its current state and future intention to traditional ships in the vicinity (Alsos, Andreas, Skåden, & Porathe, 2022). The complexity involved and the range and scope of sensors and automated systems pose a burden upon both internal vessel infrastructure and external communications channels to exchange unprecedented amounts of data and information. Considering the combined data and information-generating capabilities provided by on board sensors, navigation and engineering systems, plus the need to communicate this data along with command and control instructions to operate MASS, data transfer rates are expected to exceed 1 Gbps (gigabits per second) generating exabytes (millions of terabytes) of information that needs to be communicated and managed effectively and securely (Wright, 2020). During a salvage operation, disruptions or failures in these communication systems can hinder both remote control of the MASS and/or intervention on board by salvors. There are a number of essential forms of communication on board a MASS, which salvage operations will depend on. These means of communication will be further investigated in this section.

Global Maritime Distress and Safety System (GMDSS) is the standard international safety communication system relied upon by vessels at sea. The GMDSS is made up of terrestrial and satellite technology and shipboard radiocommunication systems. The fundamental concept of the GMDSS is to provide ships with the reliable means to raise a distress alert to shore-side search and rescue authorities and to vessels in the vicinity, in the event of an emergency where assistance is required (Ryan, 2022). Using the various communication systems within the GMDSS, ships have the ability to communicate with and automatically alert coast rescue authorities and nearby vessels quickly using separate and independent means so that a coordinated search and rescue response can be actioned with minimal delay (IMO, 2019). Regulation 16 of Chapter IV of the SOLAS convention mandates that all ships must have suitably qualified personnel on board to perform distress and safety radiocommunication functions. In terms of MASS, this mandatory requirement will be fulfilled by a designated person ashore in an RCC. Relaying a distress call for a MASS, with no one physically being on board, has two fundamental risks of not meeting the objective of relaying a distress call through the GMDSS. These risks are - not relaying accurate information due to the operator being remote in location to the vessel in distress, and not being able to communicate with the vessels if one or all the vessels' communications links are down and the connectivity link with the RCC being down. The potential of either of these risks occurring will adversely affect the salvage operation, with the salvage responders either not receiving the distress notification to respond to it or not being fully prepared or equipped in their response, due to them not having all the correct information of the incident on board.

When the subject of communication between ships is mentioned, the conversation inevitably turns to discussion of Very-High Frequency (VHF) radio, which is the single most significant technology for achieving bridge-to-bridge voice communication (Wright, 2020). VHF is mostly for general communication between ships to ship and ships to shore, allowing ships to solve confusion by communicating intent and perception (Alsos, Andreas, Skåden, & Porathe, 2022). Besides general communication, the VHF is used to broadcast the Automatic Identification System (AIS) information. AIS is an automatic tracking system that uses transponder and receiver units to identify and locate vessels by electronically exchanging data with other nearby ships, shore, and satellites (Alsos, Andreas, Skåden, & Porathe, 2022). A failure of VHF communications will result in faulty, or no AIS data being transmitted from the vessel, which will prevent salvors ability to track the vessels movements. During a salvage operation, especially during the initial stages of the salvage, general VHF communications between the salvage team and vessel are essential in exchanging information and coordinating a response on board. During a salvage response to a MASS, these VHF general communications between the on-site Salvage Master and the vessel's Master in distress, would now need to occur between the Salvage Master and the RCC. This VHF communication would need to be conducted either through a VHF relay system or an alternative method, such as satellite communications. There is a risk of communication lag, delays and potential loss/misunderstood communications in these scenarios, which could negatively affect the salvage operation.

Satellite Communications (Satcoms) will most probably be the major communication method for autonomous ships (Felski & Zwolak, 2020). Satcoms for autonomous ships are anticipated to feature a multi-layer satellite architecture to ensure continuous communication links with the vessel. This architecture will include satellites in Geostationary (GEO), Highly Elliptical Orbit (HEO), Medium Earth Orbit (MEO), Low Earth Orbit (LEO), and Satcoms 5G/6G satellites – Ref. Figure 4. There are various challenges and risks related to the efficiency and reliance of Satcoms, which include environmental and external risks (weather, topography, vessel shadow sectors, and vessel movements), as well as operational and security considerations (import/export controls, jamming, cyber-attacks and physical security) that could affect Satcoms and its connectivity capability on board the MASS and ashore in the RCC. If, for whatever reason, Satcoms connectivity is lost on board the MASS, it will invariably affect the transfer of vital information to operate the vessel. For a salvage operation, the risk of responding to a MASS with limited or no maneuverability and no means to receive/transmit information from the MASS in distress, will increase the safety risk of getting a response to the vessels location and getting a salvage team on board to reinstate operations and connectivity on board.

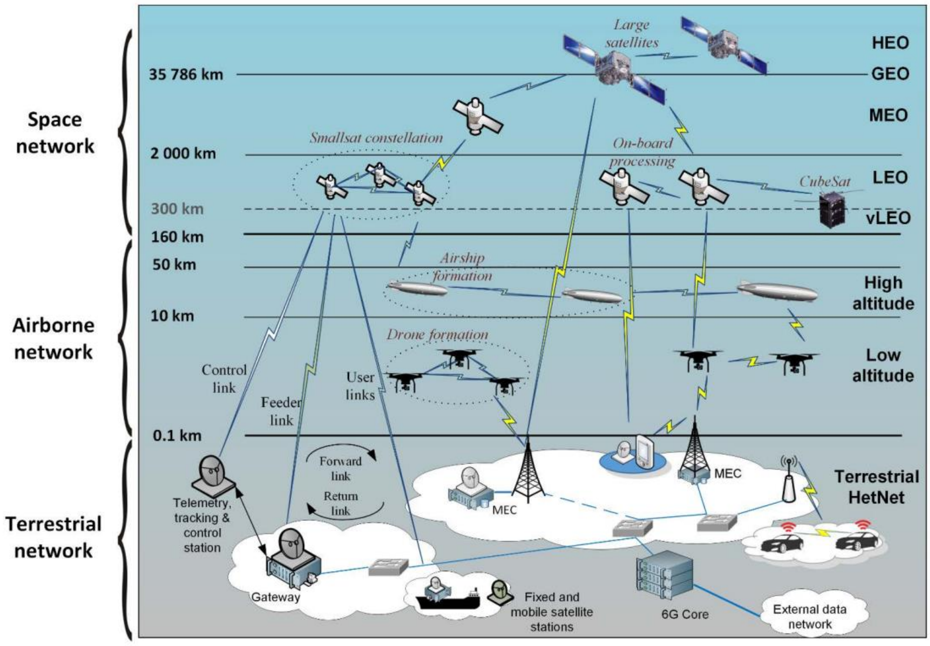

Figure 4: Multi-layer satcom architecture utilizing 6G communications (Höyhtyä, et al., 2022)

5.1.3 Cybersecurity

In 2016, the IMO officially recognised the importance of cybersecurity in that security breaches have the potential to do considerable harm to the safety and security of ships, ports and marine facilities. It issued a temporary risk management guideline (IMO, 2016), which was superseded by a formal guideline (IMO, 2017) the following year. The IMO Guidelines contain high-level recommendations for maritime cyber risk to safeguard shipping. While best practices concerning cybersecurity, with additional guidelines, being covered by BIMCO (BIMCO, 2020); UK Department for Transport (UK Department for Transport, 2023); International Organization for Standardization (ISO, 2022); and NIST Cybersecurity Framework (National Institute of Standards and Technology, 2024).

A number of studies have been carried out regarding cybersecurity and autonomous vessel operations. Research by Silverajan et al. (Silverajan, Ocak, & Nagel, 2018) considered various types of potential cybersecurity threats to autonomous vessels. The authors identified seven attack vectors that attackers could exploit: positioning systems; sensors; firmware upgrades; voyage data recorders; intra-vessel networks; vessel-to-land communications including satellite and cellular; and remote systems on the vessel accessible from the RCC. They also identified attack types applicable to these surfaces:

malicious code injection by network infiltration, removable devices or firmware update; tampering or modification of intra-vessel network packets; GNSS spoofing; AIS spoofing; signal jamming against GNSS and various sensors; and eavesdropping and disruption of the communication link between the vessel and RCC. Agamy (Agamy , 2019) further elaborates that typical cyber threat scenarios to autonomous ships would be: removable devices inserted into the on board system; taking control of the vessel through a communication link; GNSS jamming; blocking communications between the vessel and the RCC; and GNSS spoofing.

It is evident that cybersecurity is and will remain a crucial consideration for any salvage operation involving an autonomous vessel. The cybersecurity risk impacts not only the measures salvors must take to prevent breaches or exposure to threats during their response, but also influences the type of response required. Instead of the traditional mobilization of personnel, equipment, and salvage craft to assist a vessel in distress, the salvage response for an autonomous vessel might involve deploying a team of system engineers or IT experts to the RCC or directly boarding the vessel to reestablish and secure its systems and operations – Ref. Figure 5.

Figure 5: Image generated by Artificial Intelligence depicting a salvor in the traditional sense (left) and what a salvor may look like in the future (right). With a deeper meaning of how salvors will need to be multidisciplined, both from an operational and technical perspective.

5.2 Operational Risks

Operational risks for a vessel are defined as uncertainties and hazards on board while the vessel is attempting to do its day-to-day activities within its line of work or operation (Segal, 2024). Understanding the operational risks on board a MASS is crucial for ensuring its proper functioning and the safety of the vessel. In the context of a salvage operation, these risks are equally important, as they provide insight into the incident on board and guide the appropriate response. This section highlights and elaborates on the identified operational risks associated with MASS operations.

5.2.1 Lack of or No Human Crew

One of the main objectives of autonomous vessels is to make shipping safer. It is commonly believed that human errors are the main causation factor for maritime accidents. Allianz determined that 75-96% of maritime related accidents from 1912 to 2012 were caused by human error (Allianz Global Corporate & Specialty, 2019). With the hope of making shipping safer, according to the statistics, autonomous vessels are planned to have minimal to no crew on board. However, reducing crew size while increasing vessel automation does not automatically reduce the number of duties required of the remaining crew on board. Moving crew shoreside can also be argued as a transfer of human error with no actual reduction of human error within the chain (Wróbel, Montewka, & Kujala, 2017).

The lack of or absence of on board crew of a vessel being salvaged is not out of the ordinary for most salvage operations, but the actual operation and functioning of the vessel being designed for minimal or no crew means that traditional methods of salvage that rely on human presence both from a practical implication and a legal standpoint, will need to be adapted.

The crew of a salved vessel and the salvors are the primary humans present in a salvage operation and they are important witnesses (and assets) to the operation, their testimonies being material for establishing facts about the operation. The removal of the crew from the salved vessel will result in the salvor undertaking operations 'unassisted' or 'independent' (Wróbel & Suri, 2022). Following on from this, the lack of crew on board a vessel will reduce a traditional risk, (Wróbel & Suri, 2022) i.e. risk to life of the crew. However, at the same time, this would perhaps result in unassisted salvage, increasing the effort and skill required by the salvors, akin to salvage of abandoned vessels (Wróbel & Suri, 2022).

It is also foreseeable that issues with respect to the command and control of the crewless vessel itself would hamper salvage operations. To put this in context, one needs to consider if it would be a possibility to restart the engines or ballast system from a RCC or would a physical intervention for external reset be required. Given the variance in climatic conditions and the inherent danger element prompting salvage, the latter proposition seems to increase the reasonable efforts and costs akin to operations where salvors are dropped on board by a helicopter. (Wróbel & Suri, 2022)

Under normal circumstances, salvors would consult with the crew to gather additional information about potential risks. The crew would provide insights beyond the technical capabilities of sensors and control systems, ensuring that everyone involved in the operation has a comprehensive understanding of the situation. Without this input, uncertainties, difficulties and risks increase. Removing experienced personnel from ships could mean that any accident that does occur could be far more severe. A study conducted (Wróbel, Montewka, & Kujala, 2017) analysed 100 marine accidents that occurred between 1999 and 2015 using Human Factors Analysis and Classification System for Maritime Accidents. These accidents took place in varied geographical regions, with the majority of them being groundings occurring in Northern Europe. The results from this study concluded that unmanned vessels would decrease human-error-caused accidents 3:1 and eliminate on board fatalities, but there would be an increase in consequences once an accident occurs. Situational assessment, decision making, and damage control, which are all normally completed by on board crew, are no longer possible, thus increasing a vessel's consequences once involved in an accident. (Hannaford & Van Hassel, 2021)

5.2.2 Situational Awareness and Remote Operation Challenges

Throughout history, ships have been operated by people. To date, developments in automation are making it possible to further reduce or even eliminate the crew in attendance for carrying out ship functions. However, this requires that observations and decisions are made by crew off the ship (remote monitoring and control) or by the system itself by means of algorithms (autonomy) (Vartdal, Skjong, & St Clair, 2019). Whether a decision is made in a RCC or via autonomy for a MASS, the decision-making process will require adequate situational awareness to ensure the decision-making process is done taking in all or as much information it can, before making the decision.

Situational awareness can be defined as understanding the current situation. It is the ability to look, evaluate relevance, synthesize large amounts of information, and make a correct decision and act in a timely manner (Jaram, Vidan, Vukša, & Pavić, 2021). Situational awareness on board a vessel is related to what ship handlers refer to as ’ship sense’. Ship sense for a watchkeeper manoeuvring a vessel, is the ability to take in all the dynamic information on board, which could be kinetic feeling of heaving, pitching, vibration of the vessel, seeing the wave patterns, hearing the wind, wave slamming and engine sound, to then make a decision based on all or some of this information (Man, Lundh, & Porathe, 2014). For autonomous ships, situational awareness refers to the ship's ability, through advanced sensors, data processing systems, and artificial intelligence (AI), to comprehensively understand and interpret its surroundings and operational context in real-time. Situational awareness challenges for remote operations on board ships are complex and multifaceted, as they involve the integration of advanced technology, human-machine interaction, and the dynamic and often unpredictable maritime environment. For a remote operator to gain adequate situational awareness, sufficient information must be transferred from the sensors on the ship to a RCC in a timely manner. This transfer of information needs to be constant, reliable, secure and have redundancy.

In a focus group interview of participants with seagoing experience, supported by The EU project Maritime Unmanned Ship though Intelligence in Networks (MUNIN), the participants were asked questions related to operating a vessel remotely. One of the questions discussed in the focus group detailed the challenges operators in a RCC would have controlling a vessel remotely. The below table gives an overview of the discussion had.

Table 3 - Actions and confronted challenges discussion concerning shore-based ship monitoring and controlling (Man, Lundh, & Porathe, 2014)

What the operators would do	Consequences as challenges
Observe multiple screens	It must be possible to display all-needed information and allow perceiving it as onboard but it would cause information overloading problem; The operators must be considered as seafarers with expertise
Use simulator as human machine interfaces rather than mouse/keyboards	
Monitor incidents onboard Well prepare for emergency	How to handle maintenance work immediately and management (ordering spare parts)
Observe gyro and other sensors	Are they real time sensors, if so, what the cost would be
Let system calculate risks and alternatives	Ensure more backup sensors and systems on the ship to prevent / handle severe technical failure (e.g. connection lost)
Trust in the system and sensors	How to guarantee the reliability of the system so people could really trust it

Taking the challenges raised in Table 3, it is foreseeable that issues with respect to the command and control of the crewless vessel itself will also have an impact on a salvage operation. To put this in context - would there always be a possibility to restart the engines or ballast system from a RCC or would a physical intervention for external reset be required? If the answer to the latter is no, the challenges of a salvage operation on board a MASS will not only become more complex, but also the requirement for salvage assistance will inevitably increase for these vessels.

5.2.3 Salvage Equipment

At a basic level, it should be obvious that the more technically advanced a vessel is, the greater the salvage challenge. Beyond the operational difficulties already mentioned, responding to an autonomous vessel requires having the right tools for the job, which poses a realistic concern for salvors. With autonomous vessels representing the forefront of maritime technology, salvors must ensure their equipment remains suitable for these advanced ships. This means staying informed about the latest technologies and designs of autonomous vessels to either adapt their existing equipment to meet the requirements or invest in new tools to ensure compatibility.

5.2.4 Alternative Fuels

It is already widely acknowledged that fossil fuels are no longer a sustainable way of providing ships with energy, and alternatives are being sought, with MASS promising to reduce the risk of pollution by discarding conventional fuels (Wróbel & Suri, Identifying factors afecting salvage rewards of crewless vessels — lessons from a case study, 2022).

Besides the long-term benefits of alternative fuels to the environment, the use of alternative fuels on ships comes with a number of risks and challenges, not only to the design, use and storage of the alternative fuels on board, but also to salvors during a salvage operation. Below is a list of the predominant alternative fuels to be used on ships and inevitably MASS as well as their characteristics (Lloyds Register):

- Liquid Natural Gas (LNG) - boiling point -162 °C, flammable/explosive, lighter than air when T>-100 °C.
- Methanol - boiling point +64,7 °C, flammable/explosive, toxic. Can be handled at room temperature.
- Liquid Petroleum Gas (LPG) - boiling point -42 °C, flammable/explosive, lighter than air.
- Ammonia - boiling point -33 °C, flammable/explosive, toxic, lighter than air.
- Ethane - boiling point -89 °C, flammable/explosive, lighter than air.
- Hydrogen - boiling point -253 °C, flammable/explosive, lighter than air.

During a salvage operation, where a bunker/fuel tank is damaged, oil can be lightered in the event of a leak or the breach in the tank patched, which is comparatively a straightforward operation that most salvors know how to handle. But the risks from a fuel like ammonia, which emits toxic fumes and is corrosive, it is very different. The latter risks are relatively common with most alternative fuels, while the handling of methanol is considered easier than some alternative fuels, the very low temperatures and high-pressure containment of some fuels, including hydrogen and LNG, require an entirely different response. The safety risks associated to maintaining the low temperatures of the alternative fuels and finding available resources and equipment to handle these fuels in a salvage operation are at the forefront of salvors concerns when responding to a vessel powered by an alternative fuel.

Besides the concerns of salvors expected to work on board or in close proximity of the alternative fuel powered vessel in a salvage operation, local authorities where the vessel is operating will also have a concern, due to the threat of low-level toxic vapor clouds that may emit from a breached tank and drift over populated areas.

It is clear that salvage teams responding to MASS will be required to learn the properties of a series of fuels and the techniques to handle them as well as having the tools to protect themselves and the wider population.

5.2.5 RCC Security

The RCC refers to a land-based station, which is essential to enabling the remote monitoring and control of MASS from shore. The operators in a RCC may initiate remote control for general oversight of the autonomous ship or to switch to the manual mode to handle specific hazardous or emergency situations that are beyond the ship's autonomous capabilities (iTrust - Centre for Research in Cyber Security, 2024). During a salvage operation involving a MASS, effective communication and coordination between the salvors and the MASS operators in the RCC are critical for an efficient response to the vessel in distress. Maintaining a secure link between the MASS and the RCC is essential, requiring both virtual and physical security measures.

Unauthorized access or intrusions in the RCC pose significant risks, including threats to operator safety and the potential for intruders to gain physical control of the MASS. To prevent such breaches, stringent access controls must be enforced, alongside the use of multifactor authentication for remote system and network access. Additionally, measures should address insider threats, such as tampering with data or making the network and communication channels vulnerable.

Physical security in the RCC must also be robust. This includes having backup power systems, such as generators, solar arrays, and batteries, to ensure uninterrupted operations. The RCC should be protected from environmental hazards like floods, fires, earthquakes, and lightning strikes to maintain continuous functionality.

While the impact of a cyberattack on MASS systems and its repercussions on salvage operations have been discussed earlier in this research, RCC cybersecurity must be rigorously managed due to its potential exposure. System and supply chain attacks are of particular concern, given the involvement of multiple vendors working on various RCC systems. Therefore, strict IT protocols and controls must be implemented to mitigate and prevent cyberattacks on MASS systems through the RCC.

5.3 Legal and Regulatory Risks

The legal framework in general for autonomous ships is still evolving. According to research conducted by the Danish Maritime Authority (DMA) in 2017, there are seven categories where regulatory barriers exist with the implementation of autonomous shipping. They are: Jurisdictional Issues; COLREGs; The Crew of the Future; Marine Environmental Protection; Construction Requirements; Liability and Insurance; and Cybersecurity (Danish Maritime Authority, 2017).

The DMA research concluded that MASS should be regulated by the IMO, and additions to COLREGS and STCW must be addressed to include MASS and Remote Control Operators (RCOs). They also concluded that MASS should be crewed appropriately to maintain the proper safety of the vessel, crew members should be adequately trained as current licensed mariners, passenger ships cannot be unmanned due to fire safety until changes to IMO's Safety of Life at Sea (SOLAS) are made, and cybersecurity must be addressed by a vessel's safety management system.

Many shipping insurers are sceptical of the practicality of removing crew from vessels, and there is some consensus that it may take more than just a few years for laws to change for unmanned vessels to operate without crew on board (Wróbel, Montewka, & Kujala, 2017). Currently, the ship's Master is responsible for all actions related to their ship. If ships remove their on board crew, ship liability will have to fall elsewhere, such as the ship's owner. MUNIN conducted an analysis of the liability and legal issues with regards to autonomous shipping. They determined that the current legal framework can be adapted, but significant issues exist with navigation and manning laws, liability, and ship design standards and construction (MUNIN, 2016).

For a salvage operation, there might be ambiguities regarding the responsibilities and liabilities of different parties involved in the salvage. With crewless ships yet to achieve full-scale implementation, no hard data pertaining to their operational and safety record is available. It can nevertheless be expected that eventually some of them may require salvage. The latter is a service, and as such is subject to a financial coverage. The amount is ascertained in courts of law on a regular basis, with certain factors traditionally taken into consideration. These in turn are based on a long experience in evaluating the success and effort undertaken in salvaging ships in cooperation with their crews. This tradition may prove unsuccessful in estimating the reward for salvaging of crewless vessels as these are likely to have a completely different design, operational aspects, technical complexity and financial value (Wróbel, Montewka, & Kujala, 2017). Therefore, at least initially, there would hardly be any basis on which salvage reward could be calculated, due to the lack of precedent cases. It can be raised that operations in which abandoned or derelict vessels were salvaged could be used as a starting point, but these are complex cases. They are, by definition, no crew on board to aid in the operation and so the salvors must handle the situation on their own. On the other hand, such cases may not be fully applicable as there might be some degree of control over the crewless vessel performed remotely from a RCC or by the vessel's own control system. Nevertheless, it is expected that the salvage of a MASS will have greater complexity of the former and greater skill will be required to affect a salvage operation on board. (Wróbel & Suri, 2022).

6 Questionnaire Analysis

This analysis provides a summary of the responses from the targeted questionnaire distributed to 17 selected individuals, focusing on the topic of Autonomous Ships and Salvage. The questionnaires and full responses can be found in Appendix 1.

The questionnaire aimed to gather expert insights into the risks, challenges, opportunities, and future developments in this emerging industry. Out of the 17 recipients, 12 responses were received, yielding a response rate of approximately 71%. The feedback collected offers valuable perspectives on the impact of autonomy in maritime operations, particularly in relation to salvage operations, and highlights concerns, and potential solutions from industry professionals.

The first two questions regarding what sector the responded operated in or had worked in and their familiarity of autonomous vessels in the maritime industry, are excluded from this analysis as it was asked to provide context on the remaining questions.

How safe do you think autonomous vessels are? The general consensus from the questionnaire responses suggests that vessels operated autonomously with little to no crew on board are expected to be generally safer than conventionally operated vessels. However, several distinctions were noted that could affect this overall assessment of safety. These included factors such as the size of the autonomous vessel, the type of cargo it carries, the level of autonomy at which it operates, and the geographical area of operation—particularly the distance offshore. These points are highly significant, as they directly influence the technology and sensor systems required to manage and operate autonomous vessels effectively. Each variable presents unique challenges and considerations, which are critical to ensuring the safe navigation and functionality of such vessels.

Do you think that increased automation and the absence of on board crew will lower the risk of incidents on board autonomously operated vessels? The responses received indicate that while most participants acknowledge the potential benefits of increased automation, the absence of crew on board is not expected to significantly reduce the risk of incidents. In fact, while some risks may be mitigated, others may emerge, particularly those related to human intervention.

Several respondents highlighted that although automation could reduce certain on board risks, new risks may arise, particularly onshore, where human interaction is still necessary for monitoring and decision-making. A key concern raised was the lack of immediate, hands-on response to minor incidents. Without a crew on board to address small issues quickly, these could escalate into larger, more serious problems that would otherwise have been easily contained with human presence and intervention.

What do you think the top three risks are to an operational autonomous vessel? The aim of this question was to narrow down any general opinions on risks associated to autonomous vessels and highlight the perceived top three likely risks to these vessels.

Taking into account all the risks mentioned by the respondents, the top three risks associated to operational autonomous vessels were Technical Failures, which was a predominant concern identified by respondents, ranging from on board system failures, blackouts, and issues with connectivity to latency in communication. These technical vulnerabilities would have critical consequences for the operation and safety of autonomous vessels. Cyber Security was the next common concern raised in the responses, which highlighted the risks of malicious attacks on the operation of autonomous vessels. This stems from the heavy reliance of these vessels on IT and software systems, which, as identified by respondents, are vulnerable to cyberattacks and hacking. In today's digital landscape, even the most advanced IT infrastructures have proven susceptible to such threats, raising concerns about the cybersecurity of autonomous vessels. The potential for unauthorized access to control systems could lead to significant operational disruptions, posing serious safety and security risks to their operation. The last of the top three risks was Situational Awareness, where several respondents emphasized the critical importance of situational awareness in the operation of autonomous vessels, along with the associated risks if it is compromised. For these vessels to operate safely, the on board AI or remote operator must be fully aware of the vessel's environment, including real-time information on the vessels operating systems, weather conditions, nearby vessels, obstacles, and navigational hazards. Without this holistic situational awareness, the risk of errors or delayed responses to incidents increases significantly.

If an autonomous vessel requires salvage assistance, do you think it will be ‘business as usual’ for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress? Every salvage operation presents unique risks and challenges and providing assistance to an autonomous vessel is perceived to be no exception—in fact, respondents suggested it may be even more complex. Several complexities were highlighted, many of which align with the risks and challenges discussed in the previous sections of this research. These include the difficulty in accessing an autonomous vessel, particularly in remote or hazardous locations, as well as the presence of new and highly advanced on board systems that may be unfamiliar to traditional salvage teams. Additionally, respondents pointed out the challenge of overriding autonomous systems to gain manual control during an emergency situation. Communication between the responding salvage team and the RCC operator was also identified as a critical concern, as effective information-sharing is vital to coordinate response efforts and ensure safe and successful salvage operations.

Do you think the absence of crew on board an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life on board the stricken vessel?

The unanimous response to this question indicated that the lack of crew on an autonomous vessel will not delay the urgency of a salvage operation. The safety of life is and will remain the top priority in any salvage effort. Nevertheless, the goals of protecting the environment and preserving property are regarded as equally important (ISU, 2016). For this reason, the efforts and urgency of a salvage response to an autonomously operated vessels are expected to be the same for any conventional vessel in distress.

Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor? Salvors responding to conventional vessels powered by alternative fuels, as well as to autonomous vessels using these fuels, will encounter similar challenges during salvage operations. Given the wide variety of alternative fuels used on board, it is difficult to assess whether it will be harder or easier to remove, isolate, or stabilize these fuels during a salvage operation. One respondent to the questionnaire, with experience in liquefied gas carriers, emphasized the challenges and complexities associated with alternative fuels. They noted that salvors will need to possess enhanced knowledge and skills to safely manage these fuels.

Do you think salvors should receive specialized training for handling autonomous vessels? All respondents agreed that enhanced skills and knowledge will be crucial for salvors when responding to an autonomous vessels. While professional salvors are experienced in responding to vessels in distress, the advanced technology and potential risks on board autonomous vessels present new challenges. To respond effectively and efficiently, salvors will require prior training and familiarization with the specific systems and hazards associated with these vessels.

Do you believe regulations for autonomous vessel design should mandate on board emergency response capabilities for these vessels? All respondents agreed that autonomous vessel design should require built-in emergency response capabilities. These should include the vessel's ability to fulfill its obligations in responding to search and rescue (SAR) requests, as well as having on board fittings that facilitate safe and simplified assistance, such as emergency tow arrangements and manual override switches. A number of respondents highlighted the need for standardization of these fittings and capabilities on autonomous vessels. Additionally, it was noted that authorities and organizations, such as the IMO (IMO) and MASS UK Industry Conduct Principles and Code of Practice (Maritime UK, 2023), are already addressing these standards and requirements.

7 Opportunities

Given the anticipated risks and challenges of salvage operations for autonomous vessels, there are also significant opportunities for growth and development within both the salvage industry and the broader maritime sector. Here are some opportunities to enhance the efficiency, effectiveness, and safety of salvage operations on autonomous vessels.

MASS are expected to have extremely limited capabilities of responding to hazards. Only a timely reaction of salvors would help restrict the extent of damage (Wróbel & Suri, Identifying factors afecting salvage rewards of crewless vessels — lessons from a case study, 2022). This underlines the requirement for ensuring that no delays appear due to formal reasons. To avoid such complications, an opportunity of establishing a 'Global Salvage Agreement' to secure salvaging the MASS is possible. Such global salvage agreement are aimed to ensure that the crewless vessel does not leave the port without a warranty that the vessel will be salvaged anywhere in the world, or in a limited geographical area, to which operations of such vessel would be restricted, directly or indirectly by a professional salvage company with sufficient operational capabilities.

With MASS still in the development phase, this offers a prime opportunity for autonomous vessel designers, owners, and operators to collaborate with salvors. By engaging with salvors, these stakeholders can better understand the concerns and challenges associated with responding to incidents involving MASS and work together to develop solutions. This phase of development also provides salvors the opportunity to learn and understand the technical aspects of a MASS. This phase allows owners or operators of MASS the platform to share their expectations of salvors when they may require their assistance. The ultimate aim is to equip salvors with the necessary tools and strategies to efficiently handle incidents on MASS, preventing situations from escalating.

Autonomous technology and artificial intelligence are driving modern innovation across various sectors, and the maritime industry is no exception. However, the industry is still in the developmental phase of fully harnessing these technologies. Traditionally, the salvage industry has adapted to advancements in maritime technology to ensure effective responses to incidents that could impact the safety and integrity of vessels. This evolving landscape presents an opportunity for salvage companies to invest in research and explore new methods of providing assistance, which may not fall under traditional salvage operations.

There are numerous ways the salvage industry can leverage these technological developments to deliver more efficient and effective responses to vessels in need, which include remote assistance, where trained salvage professionals can offer real-time support to vessel controllers in a RCC when an incident occurs aboard a MASS they are overseeing. This approach allows salvage experts to guide the situation remotely, without the need to deploy a full salvage team to the vessel, ensuring quicker responses and minimizing costs. There is also the deployment of a MASS specifically designed for salvage operations can provide assistance to vessels in distress without risking the safety of crew members or salvage teams. These autonomous salvage vessels can be remotely controlled or operate independently, allowing for efficient and safe responses in hazardous conditions. The use of drones equipped with advanced sensors and cameras can be used to gather critical information remotely, rather than deploying salvage personnel onto a burning vessel to assess the situation, is another means of utilizing technological developments. Drones can be employed to inspect confined spaces, eliminating the need for human entry into potentially hazardous areas where gas levels may be unsafe, thus improving safety and efficiency in salvage operations.

During salvage operations, vessels in distress often require towing due to system or engine failures. In cases where there is no crew on board, salvage or tug crews typically have to board the vessel—often in dangerous conditions—to establish a tow connection. With advancements in automated systems, an automatically deployed emergency towing arrangement could be utilized. Taking into account the IMO guidelines MSC 35(63) (IMO, 1994) for tankers over 20,000 tonnes deadweight, this system could be deployed from a MASS without on board crew. The towing vessel could easily retrieve the towline, eliminating the need to put personnel in harm’s way. This approach would not only enhance safety but also save valuable time, preventing the drifting MASS from grounding or colliding with another vessel.

As legal and regulatory frameworks struggle to keep pace with the rapidly evolving technologies of autonomous vessels, varying interpretations of regulations and standards have emerged. This often leads to a wide range of designs and systems on board these vessels. Given that the autonomous shipping industry is still in its developmental phase, there is a unique opportunity for stakeholders to collaborate and work towards standardizing the design, structure, and systems of autonomous vessels. Such collaboration would not only aid regulatory bodies in ensuring the safety and compliance of these ships but also benefit operators and responders, who are responsible for maintaining their functionality and providing assistance when necessary.

8 Overview and Findings

An overview of the research on autonomous ships and salvage can be viewed in Figure 6, which outlines the three key categories of risks and challenges involved in a salvage operation on a MASS. These are technical risks, operational risks, and legal risks. Additionally, it highlights the opportunities that emerge from this area of research, which can be summarised as collaboration, global salvage agreements, standardization and innovation.

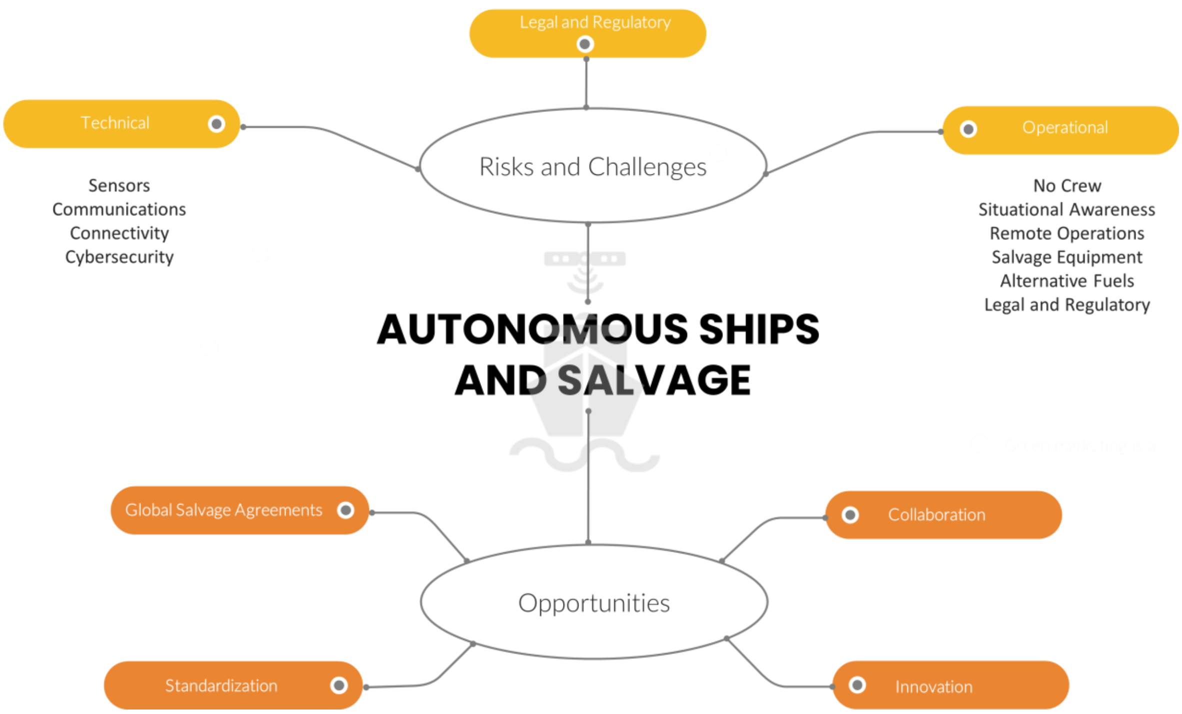

Figure 6: Research overview of Autonomous Ships and Salvage.

The research discussed in this thesis identifies several key findings. These include the critical need for collaboration among various stakeholders involved in the development and operation of MASS. It also emphasizes the importance of training and preparedness salvors and operators require to effectively handle diverse emergency situations onboard. Additionally, the research underscores that cybersecurity will be a crucial factor in ensuring the continuous functionality and safe operation of a MASS.

9 Conclusion

The evolution of maritime technology, from Tesla’s groundbreaking telautomaton to the rise of autonomous ships, marks a remarkable path of innovation. As autonomous vessels become more prevalent, it is essential to address the complexities of ensuring their safety, particularly in emergencies. The aim of this research thesis was to ensure that all stakeholders in the autonomous shipping industry are aware of what to expect in the event of an incident and know the necessary steps to prevent or mitigate such events on board a MASS.

This thesis raised and addressed three pressing questions related to MASS and salvage.

In response to the first research question— ‘What are the risks, challenges, and opportunities related to salvaging an autonomous vessel?’—this study has thoroughly examined the specific risks and challenges associated with salvaging these vessels, stressing the importance of proactive measures to improve preparedness. It explored not only the operational risks but also the technical and legal aspects that come into play.

Regarding the second research question—'Are professional salvage companies prepared, skilled, and equipped to respond to an autonomous ship in distress, or will traditional salvage techniques suffice as we move into the era of autonomous ships?’—the findings from the questionnaire reveal a clear need for salvors to be adequately equipped, trained, and ready to assist autonomous vessels requiring salvage.

The third research question—'Are autonomous ship designers, developers, and operators incorporating designs, procedures, and systems that facilitate a salvage response in the event of distress?'—highlights the critical importance of collaboration among all stakeholders in this rapidly evolving field.

It would be safe to say that the salvage industry, which has supported the maritime sector through various technological shifts, will continue to play a pivotal role in managing risks and responding to incidents involving autonomous ships. By identifying potential risks and offering tailored solutions, this research outlines opportunities for the future of MASS while upholding a strong safety framework. The insights gained underscore that marine autonomy should not be seen as a missed opportunity, but as a driving force to enhance the industry's readiness for unforeseen incidents that may require salvage assistance.

10 Discussion

Starting my maritime career in 2000 with the South African Navy, the concept of autonomously operated vessels navigating the oceans was far from my imagination. At that time, mobile cellular phones were only just becoming widely available, and communication with shore while onboard a naval vessel was extremely limited—typically just one email per week, without attachments. After leaving the Navy in 2009, I joined one of the world's largest salvage companies, where I have had the privilege of participating in and observing numerous salvage operations around the globe. This extensive exposure has greatly contributed to my understanding of the potential risks on board vessels and the critical measures needed to prevent minor incidents from escalating into full-blown catastrophes.

As discussed in this research, it is crucial for salvage companies to keep up with advancements in the maritime industry. To fulfill this requirement, salvors continuously learn from each salvage project, refining their services and studying maritime market trends to anticipate and adapt to industry developments. With the rapid advancements in autonomous vessel operations, depicted in Figure 7, the maritime industry is expected to experience significant and transformative changes. For this reason, I was afforded the opportunity to conduct this research thesis of autonomous ships and salvage.

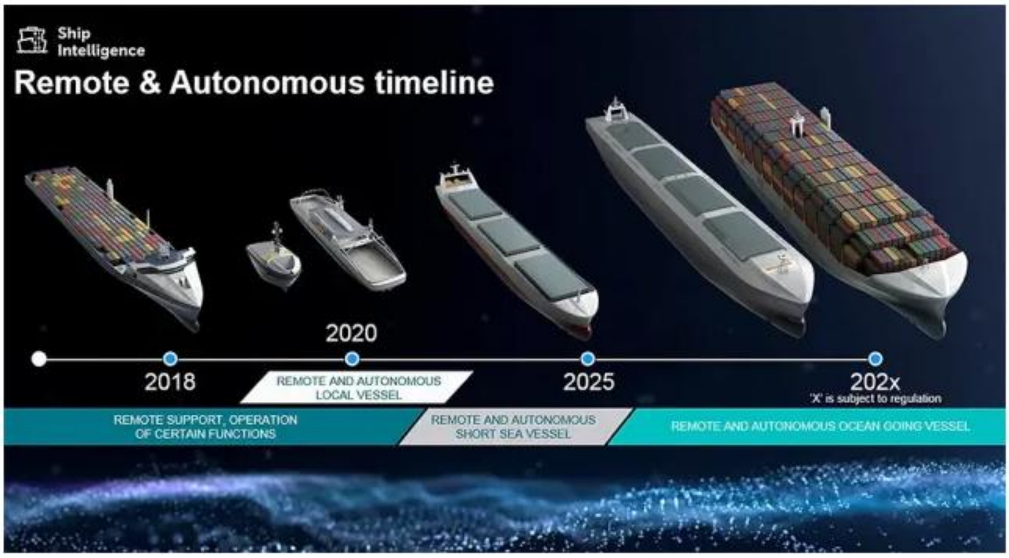

Figure 7: Projected Autonomy Timeline (The Shipyard, 2020).

Despite the anticipated growth of maritime autonomy in the coming years, several challenges must be addressed before autonomous ships become a common sight on the high seas. Nevertheless, the maritime industry faces an exciting future, with the potential to enhance safety, reduce operational costs, and boost fuel efficiency across the board.

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Appendix 1 – Survey Questionnaires

YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?
Marine and energy consulting, predominately representing Underwriters interests in marine insurance claims and warranty attendances
2. Are you familiar with the advent of autonomous vessels in the maritime industry?
Yes
3. How safe do you think autonomous vessels are?
The issue is not the safety of the vessel per sae, but rather the effectiveness of governing structures. They are as safe as conventional ships – simply shifts of risk management structure
4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?
No.
5. What do you think the top three risks are to an operational autonomous vessel?
Inadequate assessment of risk migration from conventional to autonomous vessels, thereby not providing for adequate risk mitigation or acknowledging the ongoing present of human error, whether it be in design or integration of operation; Complacency in operator management given the sense of " remote" management. This can be compared with the differentiation in crisis management in a simulator vs real situation The increased technological development in cyber space which impacts input to onboard management through remote integration. One must be mindful that there are varied degrees of autonomy
6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress? If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'
Not entirely business as usual. A large component of onboard emergency management is the complex integration of sensory inputs and uptake which allow for decision making and response. It is debatable whether Technical sensors providing inputs are suitable replacement for human processing and communication as first scene communications to salvage responders. One could argue the lack of crew onboard with good working knowledge of the casualty vessel is problematic, however a well resourced remote control center can be equally adequate to provide info required to salvors, and likely more efficiently as all info is centrally located and immediately available.
7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?
No. it will accelerate the focus to prevent pollution and secure the asset.
8. Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?
It will place additional challenge. However, salvors have needed to keep up with technological changes for decades
9. Do you think salvors should receive specialized training for handling autonomous vessels?
yes

10. **Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?**
Yes. Unmanned access boarding arrangements Suitable on board response capabilities of a generic nature for salvors which are easily and readily located, including emergency towing arrangements, localized power arrangements for winches, Remote release anchoring systems (with suitable safeties) in event of potential grounding Remote operated fire monitor activation and management, CO_2 flooding systems

Note: All Responses and Information Will be Anonymized.

YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?

Sailing on liquefied gas carriers for 18 years of which nearly 11 years as a Captain. Operations manager for a fleet of 24 gas carriers for 1 year. 17 years experience as a Salvage Master.

2. Are you familiar with the advent of autonomous vessels in the maritime industry?

Yes, monitoring the news and keeping track of developments.

3. How safe do you think autonomous vessels are?

Safe enough during normal operations but believe human monitoring will be required for some time while experience and further advancement of technology is being developed. However, proper maintenance and timely intervention on issues on board will be a challenge.
Inexperience of system operators to deal with emergencies which can take place at sea. No feeling or understanding of operators with the dynamics at sea.

On, for instance, container vessels human intervention with a smoking container will not be possible if the vessel is autonomous. This may lead to increased loss of vessels and insurance claims as it will take time for salvors to arrive on site.

4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?

Not necessarily. For the time being human creativity, ingenuity and decision making capabilities to instant react to incidents cannot yet be fully solved by automation only.

First attack response to incidents on board will not be possible by automated systems.

In the middle of the ocean human intervention will be a challenge while with a crew on board instant problem solving can take place..

5. What do you think the top three risks are to an operational autonomous vessel?

1. Black out of machinery, no power to feed the systems. I.e. dead ship.
2. Cyber security which will become increasingly challenging, accuracy of the data.
3. Education, experience and knowledge to have sufficient people available to operate the systems. In this respect, people operating the systems will require hands on experience prior operating the systems remotely in order to have a better understanding of what they are actually dealing with remotely instead of pushing buttons. Repairs or maintenance will continue to take place by humans.

6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress?
If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'

It will certainly be not 'business as usual. Reason is that we obtain a lot of information from the Captain and crew on board which will be absent if they are not there.. On autonomous vessels we shall be solely dependent on the information provided by the systems and it may be questionable whether this will be sufficient as sensors only provide data which then first needs to be analysed and interpreted. For costing reasons the amount of sensors on board will be kept to a minimum to run the vessel.

7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?

No. Reason is that there are life saving appliances like lifeboats and life rafts on board.

In my experience the loss of human life occurred during the accident/incident taking place hence prior salvors have even been notified.

8. Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?

As there are many alternative fuels, and many to be used in the future, it will be increasingly complicated and challenging to respond for salvors as an increasing amount of knowledge and solutions will be required to the specifics of the various fuels. Toxicity, cryogenic, pumpability to special tanks, safety requirements, plume control, rapid phase transition, etc.

Oil can be transported in nearly everything. With alternative fuels this, in most cases, will be a more challenging matter as special transport facilities are required for most alternative fuels. These transport facilities are not in ample supply but very limited in numbers and volume..

9. Do you think salvors should receive specialized training for handling autonomous vessels?

Yes. Especially to know where the override function is. Salvors will require increasing knowledge of automation systems. As such, team work with operators of the systems will become increasingly necessary.
Crew assistance will not be possible, other than from system operators far away, hence trouble shooting of machinery will not be possible but will be dependent on the skills of salvors.

10. Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels?
If so, do you have any thoughts what these sorts of capabilities could entail?

Yes, especially fire fighting capabilities.
With a crew on board there is always the possibility of human intervention and interpretation. For instance fighting a fire in a particular container. That will not be possible when there isn't a crew on board.
Sensors are not capable to interpret the data, let alone take action.

As of now, I am not convinced that autonomous vessels are suitable to carry each and every cargo in a safe manner especially not for ocean going vessels. Vessels trading on short voyages is for the moment maximum feasible.

Note: All Responses and Information Will be Anonymized.

YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?

Salvage

2. Are you familiar with the advent of autonomous vessels in the maritime industry?

Yes, though no experience (yet) with the salvage of such a vessel

3. How safe do you think autonomous vessels are?

About as safe as self-driving cars: they know the traffic rules but cannot handle unexpected situations as well as humans. (And traffic rules are not fail-safe to begin with).

4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?

No, human error will remain a significant factor contributing to incidents as will miscommunication. An autonomous vessel will have many different parties involved in its management and navigation, a flawless operation depends on their performance, cooperation and communication. Additional risk-increasing factor will be the inability to anticipate and prevent certain problems occurring on board because there is no crew present.

5. What do you think the top three risks are to an operational autonomous vessel?

Lack of awareness of the vessel's situation due to limited means of assessing the actual circumstances on board (a whale or a one hundred year wave about to hit will not be noticed, small oil leaks that may cause a fire in the engine room will go undetected/will not be dealt with in time), interaction with other craft/humans on the water will be delayed or absent, breakdowns and accidents will be more difficult to manage and may lead to more serious and frequent damage to the vessel and to the environment.

6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress?
If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'

Salvage is never routine, but I assume the vessel will have a manual override so she can be handled by the salvors. Communication with the remote operators of the vessel will be key,
Vessel would need to be more salvage-ready than a crewed one: have redundancy on board and also things like a permanent emergency towage connection, sufficient and effective fire fighting means, etc.

7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?

Yes, but lives and environment outside of the vessel may be at stake. In addition, accidents at sea tend to get more serious and more difficult to manage over time, my guess is the response to an accident involving an autonomous vessel will be equally urgent as mobilization to a crewed craft in trouble.

8. Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?

More challenging. Since 'normal' vessels will also be using alternative fuels, this is not a challenge specific to autonomous vessels

9. Do you think salvors should receive specialized training for handling autonomous vessels?

Yes, definitely on the technical side.
Some of the legal consequences of the vessel being unmanned will have to be investigated. There is no longer a Master on board so who can make decisions regarding how to handle the casualty on behalf of Owners? Who can speak for cargo on board?

10. Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?
See above under 6.

Note: All Responses and Information Will be Anonymized.

YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?

Marine Consulting / Marine Salvage

2. Are you familiar with the advent of autonomous vessels in the maritime industry?

Yes

3. How safe do you think autonomous vessels are?

Safety is largely a matter of perception, and at this stage, I don't believe the world is fully prepared for autonomous vessels. A hybrid model with minimal crew seems more feasible, but a fully autonomous vessel (FAV) raises significant concerns. As of now, my confidence in the safety of FAVs is quite low.

4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?

My opinion is that increased automation on ships can reduce the chances of accidents caused by human error, like fatigue or distraction, since machines are more consistent and precise. It is already established that the bulk of incidents happen because of Human errors. However, it also brings new risks, such as system failures or cyberattacks. Without a crew onboard, responding to emergencies like collisions or equipment failures might be slower, making it crucial to have strong monitoring systems in place. So, while automation can lower some risks, it also creates new challenges that need to be carefully managed.

5. What do you think the top three risks are to an operational autonomous vessel?

Emergency Response Limitations
Cybersecurity Threats
Machinery or systems failure, which requires human presence onboard

6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress?
If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'

"Business as usual" for salvage operations typically involves:

- Gathering all relevant information from the vessel in distress.
- Coordinating with the casualty's crew until salvors can board.
- Once on board, collaborating with the crew, who have an in-depth understanding of their ship.

With fully autonomous vessels, however, several new risks and challenges emerge:

- Autonomous ships would rely on data relayed via onboard cameras and satellite systems, but there would be no crew to provide real-time insights or hands-on assistance. For example, if a Fully Autonomous Vessel (FAV) runs aground, salvors would lack critical local knowledge, such as the exact nature of the seabed (whether it's sandy or rocky) and the extent of damage to the vessel's tanks. Without crew input, decisions like whether to ballast the vessel down to prevent further damage while waiting for salvors become far more difficult.
- In every salvage situation, effective collaboration with the vessel's crew is crucial, as they understand the ship's systems and structure best. The absence of a crew creates a significant operational gap for salvors. Again, if we take the grounding incident above, the crew will be aware of the systems onboard much more better than the salvor, even for simple task such as ballasting and deballasting of tanks using ships pumps.
- Additionally, the learning curve for salvors responding to an FAV will be steep, as they won't have the support of experienced crew members who know the intricacies of the ship's systems. This could slow down the salvage process and introduce new risks in emergency situations.

7.	**Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?**
No, the salvor will respond as they always do. The Salvor is a “for profit” organization, who are keen to make profits from the salved vessel. Salvage works never mobilize for saving human life as that is always undertaken by the Coast Guard and other vessels in the vicinity.	
8.	**Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?**
The use of alternative fuels on autonomous vessels will indeed pose challenges for salvors, as the learning curve for each vessel type will be steep, potentially slowing down salvage operations. Beyond the salvage itself, local support teams at the incident site will need to be prepared to handle the specific challenges posed by alternative fuels, including the associated risks and emergencies. This requires readiness and training to effectively respond to these new fuel types, adding complexity to both the salvage and emergency response efforts.	
9.	**Do you think salvors should receive specialized training for handling autonomous vessels?**
Absolutely Yes	
10.	**Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?**
Yes, I believe autonomous vessels should have onboard emergency response capabilities. Here's what these capabilities could include: - A dedicated standby team onshore, possibly located at multiple global stations, well-trained in the specifics of the vessel and ready to be deployed to the site immediately if external support is needed. - Access to all technical drawings, models, and schematics, readily available for rapid deployment to assist in emergencies. - Comprehensive information about the cargo, particularly for container ships, ensuring full visibility and traceability of all cargo on board. - A partnership with preferred salvage companies who are specifically trained to handle autonomous vessels. - 3D mapping of the vessel to support simulations and emergency response planning.	

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YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?

Authority - SAMSA

2. Are you familiar with the advent of autonomous vessels in the maritime industry?

Yes

3. How safe do you think autonomous vessels are?

Properly implemented, I am of the opinion that it will increase the safety of vessels, subject to supporting systems like Aids to navigation improving with them.

4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?

I do think that it will lower the risk. I do not believe that we will be able to get rid of crew onboard for the foreseeable future.

5. What do you think the top three risks are to an operational autonomous vessel?

1. Malicious intervention of the vessel and systems by people or systems to do harm.
2. The inability of the vessel and its systems to detect and act on things so out of the norm (like moving away from a vessel or port/berth on fire.
3.

6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress?
If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'

No, system redundancies might still be operational and a vessel like a vessel with a burning accommodation block might want to avoid a collision with a tug that is trying to put out a fire.
Salvage by its nature however is normally out of the box thinking, so I don't think it will be a major change, but not "business as usual"

7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?

The response for salvage is very seldom for the risk to human life only and as such I believe the urgency to respond as soon as possible will remain the same.

One should also consider that the salvage vessel might be unmanned and could place herself in a position of greater risk if no people are onboard to perhaps save a vessel or people on the stricken vessel.

8. Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?

I think that this will perhaps require additional considerations when responding to a salvage. The fact that we are taking risk to life out of it, could open the options of new and unexplored options.

9. Do you think salvors should receive specialized training for handling autonomous vessels?

Yes

10. Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?
Yes, even though I do not know what capabilities, standardization would be very important. A good example will be something like the international shore connection. If one has an “international overriding unit” for specific systems, and “international towing connection” standardizing and simplifying the connection process, an “international boarding attachment area” (to attached a standardized boarding arrangement\ladder) it will greatly improve reaction times and the ability of salvors to respond

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YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?
Autonomous shipping consultancy, general maritime Master Mariner consultancy, ad-hoc seafaring roles. Previously: seafaring roles, HSE Manager, DPA, Autonomous Shipping Manager
2. Are you familiar with the advent of autonomous vessels in the maritime industry?
Yes
3. How safe do you think autonomous vessels are?
I think it depends how we define 'autonomous'. A lot of 'autonomous' (including remotely controlled) vessels currently are USVs – almost exclusively sub-24m with lesser regulatory demands, with lesser competency requirements of operators. I do not consider much of these vessels to be safe either in terms of a robust construction or in terms of safe management and operation.
4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?
If done properly, including a proper and robust regulatory framework, yes. Depending on how 'autonomous' such vessels are – if still human-in-loop then there will still be human element risk, potentially to a greater amount than traditional. If truly autonomous, there will need to be a robust assurance of human-on-loop involvement, including at software engineering level, to ensure the autonomy is robust enough to lower incident frequency.
5. What do you think the top three risks are to an operational autonomous vessel?
1) Degraded connectivity – bandwidth, latency, availability, frequencies available, blind spots. 2) Human element – specifically for remote controlled vessels and especially in the first 10-15 years when we are learning the risks and operational necessities of these vessels. 3) Length of time before we get robust regulations in place. Risks we will have grandfathered risky vessels and operations for years to come.
6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress? **If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'**
Risks of boarding a vessel not only with no people but not designed for people. Risks for vessels that might not have onboard controls or controls that salvors are typically used to. Decks, walkways etc. not designed for human transit. Ships potentially designed with different criteria to standard SOLAS ships with exemptions such as fire extinguishing means which could hamper salvage efforts.
7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?
Potentially, although it will still depend on the risk to the marine environment. We have had many cases where crew have been successfully rescued but there is still urgency due to pollution risk. A lot depends of course on the proactivity (and insurance cover) of the company involved, the Coastal State. There certainly are recent cases where, once crew were rescued, urgency was reduced which could point to this being an issue with uncrewed vessels in certain Coastal State waters, unless regulations are tightened up.
8. Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?
Depends on the reason for the salvage. It may have no impact at all, or it may make it more challenging e.g. if the salvage is due to an ESS thermal runaway, or with the presence of ammonia, LNG or other fuels more hazardous to salvors than MGO. However, if the alternative fuel is wind power (e.g. sail drones), it could make it less

hazardous as we have seen the Iranians successfully hijack a sail drone by lassoing it – so a simple job for a salvor!
9. Do you think salvors should receive specialized training for handling autonomous vessels?
Yes, in understanding different types of autonomy, modes of operation, operational envelopes – and of course this should anyway be addressed as part of regular Risk Assessment updates covering all ship types a salvage company could attend to.
10. Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?
Yes. Some sort of 'salvage controls' as well as towage points etc.

Note: All Responses and Information Will be Anonymized.

YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?

Marine Salvage and emergency response

2. Are you familiar with the advent of autonomous vessels in the maritime industry?

I am reasonably familiar.

3. How safe do you think autonomous vessels are?

I have concerns re the safety of autonomous vessels
.

4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?

In my opinion increased automation may well reduce the risk of incidents onboard autonomously operated vessels, my concern is the response capability to incidents that do occur on vessels that are unmanned

5. What do you think the top three risks are to an operational autonomous vessel?

1). When an onboard incident such as an explosion or a fire disables or reduces the efficiency of the communication system enchanting enables the onboard responses to be controlled remotely.
2). When an onboard incident is serious enough to require immediate third party physical intervention and there are no onboard crew to facilitate such intervention
3). There will be certain incidents that occur on board, the correct response to which would require the interpretation of the seriousness of the situation to be carried out by someone physically onboard the vessel

6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress?
If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'

It will certainly not be business as usual for salvage companies in most incidents on autonomous vessels where salvage services are required.
In my opinion the biggest challenge for the salvor would be ensuring the safety of the salvage crew operating in a potentially extremely dangerous environment without the assistance input from crew members who are familiar with the vessel and can advise salvors of the details and effect of the incident.
Salvors invariably require the assistance of the vessels technical staff to assist and advise with the operation of the vessels machinery and equipment which might be needed in the salvage operation. It would be difficult for this to be done remotely.

7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?

Definitely not. In effect I would suggest the opposite is true.In most incidents where a vessel requires the response of a salvage company, direct communication between the salvage company and the master is established so that the master can be advised as to what actions should be undertaken immediately while the salvage team is being mobilised. In an unmanned vessel there is very little that can be done until salvors arrive on the vessel.

8.	**Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?**
In my opinion the use of alternative fuels is still in it's infancy with considerable uncertainty in many areas that still need to be resolved. For this reason I believe effects of that in the early days of autonomous vessels that are using alternative fuels salvors are going to face new challenges when there services are required. However as more understanding of the effects of alternative fuels and salvors gain more experience and training in this field these challenges will be overcome.	
9.	**Do you think salvors should receive specialized training for handling autonomous vessels?**
There is no doubt that salvors should receive specialized training in this field in order to ensure that they operations are carried out safely and efficiently.	
10.	**Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?**
Definitely.	

Note: All Responses and Information Will be Anonymized.

YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?
Administration
2. Are you familiar with the advent of autonomous vessels in the maritime industry?
Yes
3. How safe do you think autonomous vessels are?
It depends on different aspects, as level of automation, design, connectivity, distance to shore, kind of cargo… Being in an initial stage of development, safety should be a primary concern
4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?
Mostly depends on the duplication of equipment, the reliability of systems on board and the connectivity. At this point, nothing indicates that an autonomous vessel without crew will be safer than a conventional crewed one
5. What do you think the top three risks are to an operational autonomous vessel?
Engine failure, systems failure, loss of signal
6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress? **If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'**
New challenges will exist, as the lack of help from crew, but in this case could be a salvage very similar to the one carried out at an abandoned ship. The procedures in case of salvage should be included in the emergency response system, or similar system.
7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?
I mean that SAR operations should be addressed first, salvage should be considered from a lack of risk to people on board perspective.
8. Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?
Some alternative fuels may pose an additional risk, as it may happen with other power plants based on electrical or nuclear energy
9. Do you think salvors should receive specialized training for handling autonomous vessels?
I mean that standardized systems and salvage procedures regarding MASS are of paramount importance
10. Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? **If so, do you have any thoughts what these sorts of capabilities could entail?**
Yes. A chapter of the MASS Code will address this matter. Among the contents, would add contact with company, ROC and Class. The detection of failures and the state of ship and its systems are not enough, and the standardized systems and salvage procedures should be considered

Note: All Responses and Information Will be Anonymized.

YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?

Naval, Salvage, Offshore(all areas), Training / Lecture DP Courses, Training / Lecture Navigation Systems, Base / Country Manager / Survey

2. Are you familiar with the advent of autonomous vessels in the maritime industry?

Yes, I have done some personal research as I like / support technologies that work as it falls in line with DP principles and has potential future implications throughout the industry.

3. How safe do you think autonomous vessels are?

To be determined but with good Internet coverage with excellent refresh rate / speed / onboard sensors / remote monitoring it has potential.

4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?

Yes it can lower incidents dependent on the crew qualifications / training / sensors / connectivity / remote monitoring. Further vessel design in terms of maintenance / docking schedules / class surveying /operating, monitoring and technical / marine crew training will need to adapt.

5. What do you think the top three risks are to an operational autonomous vessel?

Navigation / propulsion & steering failure / remote monitoring failure.

6. If an autonomous vessel requires salvage assistance, do you think it will be ‘business as usual’ for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress?
If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'

There will be a multiple of new risks. Access to the vessel ie structure / cargo as it will need to be locked up to prevent piracy. Taking control / command of the vessel to move it out of harms way will need well qualified salvors as there will be no crew knowledge to advise. Assessing the situation if the vessel is in peril is normally done / partially done by the crew, now salvors will need to access and determine what is required so it will take more time and more risk. There should be emergency instruction for salvors ie letting go anchor / starting engines / DP(autonomous) procedures etc. Salvors will need knowledge on an electrical / electronic technical level to repair connectivity issues.

7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?

Urgency should be same, level of risk should reduce for boarding / saving people as there is still a risk to other vessel / environment.

8. Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?

More challenging as there would need to be specialized technical experience from salvors. For example if electrically battery packs need to be isolated and specialized fuels / nuclear / green hydrogen needs to be handled in a different way than hydrocarbons. SMPEP / SOPEP incidents may reduce but a new level of containment / handling for special fuels / energy sources need to be developed and approved by Owners / IMO / IMDG / Class / Flags and Port states.

9. Do you think salvors should receive specialized training for handling autonomous vessels?

Yes definitely as per Pt 8.

10. Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?
Yes, new regulations of containment / handling for special fuels / energy sources need to be developed and approved by Owners / IMO / IMDG / Class / Flags and Port states. Special clothing, chemical suits / hi voltage suits, non ferrous metal salvage equipment / entry procedures / DP(autonomous) procedures

Note: All Responses and Information Will be Anonymized.

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?

I work in the legal sector, specifically specializing in maritime law, which includes areas like shipping, salvage, maritime contracts, and disputes related to maritime operations.

2. Are you familiar with the advent of autonomous vessels in the maritime industry?

Yes, I am familiar with the increasing presence of autonomous vessels in the maritime industry. The legal implications, including issues surrounding liability, salvage, and contractual frameworks, are becoming more prominent as technology advances.

3. How safe do you think autonomous vessels are?

Autonomous vessels have the potential to be highly safe, given their reliance on advanced sensors, AI, and automation. However, they also bring new risks, such as cyber vulnerabilities, software malfunctions, and challenges in emergency responses, which could affect their overall safety.

4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?

The absence of human error could reduce certain types of incidents, but it introduces different risks. For instance, technical failures or communication disruptions could become more significant, and without a crew to react in real-time, the consequences might escalate.

5. What do you think the top three risks are to an operational autonomous vessel?

1) **Cybersecurity threats** – Autonomous vessels are vulnerable to hacking or system manipulation.
2) **Technical failures** – Software bugs or hardware malfunctions could compromise the vessel's operation.
3) **Lack of human intervention** – In emergencies, the absence of a crew could hinder timely, adaptive decision-making.

6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress?
If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'

There will likely be new risks and challenges for salvors. For instance, salvors may need to engage with complex software systems or remote operators rather than a crew, complicating communication and coordination. Additionally, salvors may face increased technical challenges if the vessel's systems are compromised during distress, or if there's a lack of standardized interfaces for remote control.

7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?

While the absence of crew removes the immediate risk to human life, the urgency may remain high, especially if environmental hazards or risks to valuable cargo are involved. Autonomous vessels could still pose a danger to other ships, the environment, or themselves, requiring swift salvage action.

8. Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?

The use of alternative fuels could introduce additional complexities for salvage operations. Salvors will need specialized knowledge and equipment to safely handle and neutralize risks associated with alternative fuels, which might be less familiar or more hazardous compared to conventional fuels.

9. Do you think salvors should receive specialized training for handling autonomous vessels?
Yes, specialized training is essential. Salvors will need to understand the unique systems and technologies used on autonomous vessels, including how to remotely interact with and control such ships, manage software issues, and handle alternative fuels safely.
10. Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?
Yes, regulations should mandate emergency response capabilities. These could include automated distress signals, remote control interfaces accessible to salvors, fail-safe shutdown systems, and onboard fire suppression systems. Additionally, redundancy in critical systems and backup power supplies should be considered mandatory.

Note: All Responses and Information Will be Anonymized.

YRKESHÖGSKOLAN NOVIA

Questionnaire: Autonomous Ships and Salvage

Please type your answers in the open blocks below the questions.

1. What sector of the Maritime Industry do you or have you work in?

Coastguard

2. Are you familiar with the advent of autonomous vessels in the maritime industry?

Yes

3. How safe do you think autonomous vessels are?

It will depend on the reliability and effectiveness of the technology to navigate the ship and prevent collisions, groundings, etc.
There is a lot of testing and trials to undertake.
A big issue may be how reliable and safe are such vessels once they age: systems and equipment will start to become unreliable and break down more often. A ship that has no one on board to repair or manage failures may be dangerous to other vessels and the environment – until salvors can arrive to take control of the situation.

4. Do you think that increased automation and the absence of onboard crew will lower the risk of incidents onboard autonomously operated vessels?

It may very well lower the instances of collisions, allisions and groundings because the automated technology may be much more reliable and accurate than humans. However, there may be other problems associated with the fact that the ship has no, or few, humans on board to maintain things and repair failed equipment or systems, and to manage the vessel in an emergency.

5. What do you think the top three risks are to an operational autonomous vessel?

- Technology failures
- Breakdowns
- Humans intervening where the autonomous or automatic systems would have done a better job e.g. a collision caused by human operators causing a problem that would not have existed if they had left the machine to resolve it.

6. If an autonomous vessel requires salvage assistance, do you think it will be 'business as usual' for salvage companies or there will be new risks and challenges in responding to an autonomous vessel in distress?
If yes, could you please elaborate on what these risks and challenges may be. If no, could you please elaborate why you consider it will be 'business as usual'

New risks and challenges:
Salvors may be the only humans going aboard a vessel that needs assistance. There will need to be access to allow them to board and work on board. They will need to take control of the vessel, perhaps from on board the ship, in a conventional manner (from the bridge). There will need to be facilities for human habitation whilst people are on board – which may be many days, or portable facilities will have to be created and put on board vessels from salvage vessels.
There will undoubtedly be other challenges and problems created by autonomous vessels that have not yet been considered – these will be revealed by accidents and incidents.

7. Do you think the absence of crew onboard an autonomous vessel will affect the urgency of a salvage response, given that there is no risk to human life onboard the stricken vessel?

The urgency is about saving the vessel and preventing it from polluting the environment and causing damage or hazards to other vessels or structures at sea. Salvors are normally brought in after search and rescue operations are completed and people at risk have been removed / rescue.

There is a major challenge if ships break down in deep ocean: they will be a long way from engineering assistance and means will have to be found to get engineers and technicians on board. This may take days if they have to come by sea.	
8.	**Given that many autonomous vessels are expected to be primarily powered by alternative fuels, thus do you think the use of alternative fuels on an autonomous vessel will make the salvage operation easier or more challenging for the salvor?**
Depends on the volatility of the fuel – if it is highly explosive e.g. hydrogen, or corrosive or harmful to humans e.g gases or chemicals, then there will be new hazards and dangers. Oil based fuels are hazardous to humans but are a well known substance that can be handled readily and people can be protected from it.	
9.	**Do you think salvors should receive specialized training for handling autonomous vessels?**
I have no doubt they will do and are already working on this problem. The salvage industry is very adaptable and learns very fast	
10.	**Do you believe regulations for autonomous vessel design should mandate onboard emergency response capabilities for these vessels? If so, do you have any thoughts what these sorts of capabilities could entail?**
Yes. IMO is already discussing this. These ships should also have capabilities and functions that enable them to carry out their obligations to respond to search and rescue requests, particularly the ability to search for and locate persons in danger at sea and to recover them on board and provide basic welfare, medical assistance, sustenance, and communications with shore.	

Note: All Responses and Information Will be Anonymized.