University of KwaZulu-Natal

The Potential Impact of Maritime Autonomous Surface Ships on Seafarer Employment

by

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Acronyms

AB - Automatic Bridge

AS - Automatic Ship

CA - Constrained Autonomous

CS - Conventional Ship

DC - Direct Control, no autonomy

FA - Fully Autonomous

ICT - Information and Communications Technology

IMO - International Maritime Organization

MARPOL - Marine Pollution

MASS - Maritime Autonomous Surface Ships

MASS$_{UK}$ - Maritime Autonomous Ship Systems

MSC - Maritime Safety Committee

NFAS - Norwegian Forum for Autonomous Ships

OECD - Organization for Economic Co-operation and Development

OETS - Oceans Economy and Trade Strategy

REAI - Recommendation on the Ethics of Artificial Intelligence

RC - Remote Control

RCC - Remote Control Centre

SOLAS - Safety of Life at Sea

STCW - Standards of Training, Certification, and Watchkeeping

ULCC - Ultra Large Crude Carrier

ULCS - Ultra Large Container Ship

UMS - Unattended Machinery Spaces

UNCTAD - United Nations Conference on Trade and Development

UNESCO - United Nations Educational, Scientific and Cultural Organizations

VLCC - Very Large Crude Carrier

VLOC - Very Large Ore Carrier

Selected Definitions

Automated – A procedure that is well defined and can self-execute within the set boundaries.

Autonomous – An automated procedure that has the capability of learning and expanding the initially defined and set boundaries

Conventional Ship – A ship that is commonly known at the time of writing this dissertation, which is predominantly one with limited automation and operated by a crew.

Crew – A group of people tasked with the operation of a vessel from within its physical boundaries

Operator – A person tasked with the operation of a vessel from outside its physical boundaries

Remote Location – An environment outside the physical boundaries of the ship being operated

The goal Ship – a ship that is at the highest level of autonomy according to this dissertation; a fully autonomous one.

Transition period – This is the period of innovation (cyclic development, testing, industrialization, operation, and improvement) starting from the conventional ship and extending the goal ship

Abstract

In search of ways to run their ships more efficiently and safer, Shipowners are looking at limiting human involvement by employing maritime autonomous surface ships (MASS). The MASS levels of autonomy, which will result in varying degrees of human involvement reduction, are still being defined by various bodies. To assist all parties involved in this journey of MASS development and introduction, some classification societies are creating regulatory and guiding documents or instruments. Meanwhile, policymakers globally have their eye on the Blue Economy as a source of solutions to many problems, chief amongst which is employment. Also known as the Oceans Economy, Blue Economy will result in higher demand for transport of goods and persons to, from, and through the sea. Seafarer job increases are therefore among policymakers' targets.

This dissertation seeks to investigate the potential impact that the successful introduction of MASS will have on seafarer employment. It does this by analysing five classification instruments to see if there is convergence in their approaches toward MASS introduction. The five instruments are dissected for in-depth exploration before being transformed into a standardized format for comparison against each other. This standardized format maps the involvement of humans, a ship's systems, or a combination of both for some six selected functions – themes – that define a vessel's autonomy. The format also maps the physical locations of human beings for each degree of autonomy per document covered analyzed.

The findings predict strong convergence in the MASS adoption approaches, which certifies that the world is aligned in its thinking. From this convergence, it is inferred that collaborative approaches, whether direct or indirect, will result which in turn will improve the chances of successful MASS introduction. The reduction in seafarer employment, which will result based on the convergence established will however be non-linear: It will start at a slower pace as with lower autonomy saturation in the market. As time advances, more MASS and ships with higher autonomy degrees will be built increasing autonomy saturation in the market. At some point, lower seafarer employment will emerge, exacerbated by the decline of today's conventional ships which will be demolished as they reach the ends of their useful lives. Each demolition will result in job losses.

When the market is saturated with autonomy – meaning that almost all ships are fully autonomous – mariner employment will be minimal and Remote Control Centre (RCC) based. As much as 95% of the peak of mariner employment (yet to be reached) will be lost when this

MASS full saturation is reached. The timeline will depend strongly on the speed of technological advances.

Policymakers are advised to take caution with the employment prospects of mariners. Shipowners and builders are advised to collaborate on a global scale to speed up and synchronize MASS development. Training and educational institutions are advised to gear up for teaching skills required for MASS. Maritime legislators are advised to keep a close eye on legislation development aimed at accommodating MASS. Finally, Further research on timelines for MASS implementation is recommended. This will clarify the rate at which employment will evolve in the sector.

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Chapter 1

1.1 Introduction

As new technological advances are achieved, changes in the way humans interact with the world around them become inevitable. New technologies continue to emerge and are being constantly improved upon as bodies of knowledge in various applied science fields grow. This trend has existed in the past, still exists today, and will surely continue in the future. Over the past centuries, technological improvements have, for instance, allowed industries to evolve from heavy and manual labour-intensive work arrangements to the use of water and steam to mechanize production. This is now known as the first industrial revolution. Further technological advancements allowed the world to move into the second industrial revolution through the presence of electricity which enabled mass production. Currently, the world finds itself in the later and early stages of the third and fourth industrial revolutions respectively – with the former initially introduced by the introduction of electronics and computing capabilities, and the latter by the fusion of technologies that blur lines between the digital, physical and biological divides (Schwab, 2017; Philbeck & Davis, 2019).

The maritime transport industry has not been left out in this continued quest of identifying and adopting new technologies. One of the most recent technologies that have been gaining more traction as it became more widely researched has been the idea of autonomous ships (Komianos, 2019; Wright, 2020). This comes as no surprise because other parts of the transport industry have taken a lead in such endeavours. There have been successes in some sectors such as aviation for instance (Terwilliger et al., 2017); and there are strong indications of wide adoption emerging in others such as the automotive sector for instance (Jurgen, 2013; Atwell & Lăzăroiu, 2019).

In the maritime sector, the introduction and wide adoption of Maritime Autonomous Surface Ships (MASS) are expected to eliminate the human factor, which has a large cost burden attached to it in remuneration and extensive proneness to errors during decision-making and control of ships. This undertaking will result in improved efficiencies and reduced operating costs for Shipowners and operators. Humans and their intelligence are to be largely replaced with the fast-computing capabilities of modern computers, which will control technologically advanced machinery and systems in the shipping industry (Komianos, 2019). The level of human substitution will depend on the various degrees of autonomy that will be adopted (Wright, 2020). The main question therefore is: what are these levels or degrees of autonomy and how will they affect the employment of mariners in the maritime industry? This is a critical question that begs attention as employment – the lack thereof especially – in various economies becomes more topical (ILO, 2020; UNDESA, 2019).

1.2 Research Problem

Three issues are topical around the merchant maritime industry, and it is argued that a lack of their evaluation in relation to one another may lead the maritime industry into a disastrous situation. Below, the three topical issues are summarised before formulating the research problem:

(a) Labour market: Mariner shortage and related issues

First of these is the issue of a shortage of mariners. This is a widely reported and ongoing concern for the maritime industry. Trends, statistics, and strategies to combat its growth have been written about by authors including Wagtman and Poulsen (2009), Thai et al. (2013) as well as Clayton (2017). Among the reasons for this growing shortage is the lack of attractiveness for getting into the industry owing to difficulties for the persons exiting it to integrate back into the land-based job market post time at sea (Thai et al., 2013). To counter these, employers in this industry invest a lot to attract and retain employees in their organizations (Clayton, 2017). The seafarer shortage results in less-skilled individuals performing jobs that they are not qualified for and working shifts longer than they are supposed to. These further result in increased fatigue and reduced efficiencies, which in return result in increased probabilities and occurrences of accidents (Che Ishak et al., 2019). The ultimate consequences are increased operational costs for shipowners, who traditionally are the real employers in this sector (Ammar, 2018).

(b) Shipowners: Technology as a mariner-related issue solution

Second in this topical issue list of three is as much a direct result of the above labour-related issues as it is a consequence of the rate of growth in technological advances. Shipowners are starting to focus on technology to solve their mariner-related problems: high costs as a result of their scarcity, their decreased efficiencies, their cost of training and retaining, and their erroneous tendencies which often lead to accidents. Shipowners are strongly focusing on automation in their vessels – from the automation of sub-systems as they have done with the bridge (Lützhöft & Dekker, 2002; Pazouki et al., 2018) for example, to fully autonomous ships which will, as they aspire, require no humans onboard once fully established. Design and test efforts are underway (E-Navigation, 2019) and fully autonomous vessels could be operational before the turn of the current decade.

Despite the progress made in MASS development, a lot still needs to be understood and defined from both technical and legislative perspectives. The levels of autonomous configurations are yet to be fully outlined by many countries, and agreed upon globally, as is the case but even more so for the legislative framework that will allow for the harmonious co-existence of manned and unmanned vessels possible.

(c) Policymakers: Maritime sector's Job-creating potential

Third and final to this list is how, owing to the expected continued growth in international and inter-continental trade (UNCTAD, 2020) the increasing demand for shipping presents the maritime sector as being among possible solutions to job creation in some countries. The 'untapped blue economy' is among the phrases used to describe the potential that the ocean promises. South Africa's Comprehensive Maritime Transport Policy is one such policy that recognizes the maritime sector as having job-creating potential (DOT, 2017, p. 6 par. 4).

Maritime surface ships are an important part of this blue economy. In their current state, they provide jobs on board the vessel, but this will soon change if the efforts and aspirations of the Shipowners materialize. Are policymakers aware of this direction toward autonomous ships? Do they understand the potential impact the wide adoption of MASS may have? How will this impact the policies being drafted?

Statement of the research problem

The problem here is that if Shipowners succeed in implementing autonomous ships – an initiative that is not impossible in an industry that is yet to see its peaks in demand for its services – there will potentially be an impact on employment levels in the maritime sector, and in particular, that of seafarers.

Governments and policymakers on employment around the world need to know about the magnitude of this potential impact. Shipowners are understandably aiming toward substituting humans with automation and policymakers need to understand the potential impact of this on their plans. There is no understanding of what the seafarer job impact might be and there seems to be no research about this. Will mariners become obsolete or merely shift from being on-board-a-ship based to being shore-based; will some employment aboard still exist, and if so then how will it look; will this directly reduce employment in the maritime industry but indirectly increase employment in other sectors? One cannot say outright what the impact will be, but with research effort, all or some of these questions could be answered.

However, the starting point should be to expand the scope of the investigation into MASS. There is a need to understand what work has been done already relating to MASS classification, see if there is alignment in the work done if any, and understand details like milestones if any.

1.3 Rationale

The maritime sector is arguably the most important in the world. The first view is that despite a product or a service being locally made or rendered respectively, part of the value chain to get that product or service to a consumable state by an end-user involves maritime transportation at some point. Secondly, the number of people employed in the sector both directly and indirectly, as well as the potential employment creation prospects it has, are significant. For example, the sector maintained a total direct employment inventory of 1.20 million ratings and officers between the years 1990 and 2005 (Wagtman & Poulsen, 2009). That total employment count reached 1.65 million by 2015 (Clayton, 2017) and had grown to an estimated 1.89 million in 2021 according to BIMCO (Srinivasan, 2021). Some 350million indirect jobs were reported as being linked to the oceans globally, resulting in some 3 billion people relying on them for their livelihoods (UNCTAD, 2016). From a job creation spill-over perspective, Anno-Frempong (2021) estimated that the ship repair and refurbishment industry in South Africa could potentially introduce between 22,000 and 38,000 new jobs by the year 2030.

These employment and potential employment numbers above, whether looked at in isolation or together, are reason enough why the slightest change in the sector needs thorough investigation and understanding before commitments are made. Both the global supply chain and a significant number of livelihoods would be negatively impacted by a miscalculated move. This study contributes to the mitigation of that risk. This study will be a great contribution to policymaking – especially in the education and employment creation spheres of governments, but also in the legislative aspect of the maritime sector. Finally, this study will also help clarify how labour will be affected and avoid ill-informed mariner career interest shifts. More mariners could, in fact, still be required in the years to come even with MASS fully adopted, fully operational, and dominating.

1.4 Goal of the Study

The primary aim of this study is to explore and estimate the potential impact of MASS on the employment of mariners in the maritime sector. It aims to do this by first exploring and contrasting the levels of autonomy proposed to be adopted for MASS, and if extremely varied, establishing which are most likely to materialize.

The study will then move on to exploring occupations on a vessel with a size of 3000 Gross Tons or more, and with propulsion power of 3000kw and above to establish which of them are likely to be affected by various MASS autonomy degrees. Ships meeting these size and propulsion criteria are chosen because they attract the greatest number of deck officers and engine room officers respectively. For the latter – engine room officers on a ship with propulsion power of 3000kw and more – the number of mariners is increased further when the vessel is not classed for UMS (IOM Ship Registry, 2014).

Finally, the two outcomes will be analysed to estimate the most likely impact on mariner employment.

1.5 Research Questions

The main research question is:

- What is the potential impact of the introduction of MASS on the employment numbers of seafarers?

To answer this question, the research will evaluate specific sub-questions focused on unpacking MASS and seafarer occupation on board a merchant vessel with propulsion power higher than 3000kw and an overall size of 3000 gross tons or more.

Concerning MASS, the study will answer the sub-questions:

- What proposed levels/classifications of MASS exist currently?
- To what extent are the approaches convergent or agreeable with each other?
- If extremely varied; that is, divergent or not agreeable, then which are most likely to be adopted?

In respect of seafarer occupations, the study will answer the sub-questions:

- What are the current mariner occupations – both officers and ratings?
- Which and how many of the occupations are likely to be affected within each MASS classification/level or degree of autonomy?
- By how much will this impact differ, across different types of vessels, if at all?
- What will the overall impact be; how many jobs will be eliminated, how many will be substituted, how many will be shrunk, and how many will be enlarged?

1.6 Literature Review

1.6.1 A Vessel's Crew

Current-day ships require a crew – sometimes referred to as mariners or seafarers – to operate. The size of this crew differs depending on factors such as the size of the ship, the magnitude of its propulsion power, its complexity, the flag it flies, whether it is a coastal ship or a sea-going vessel, etc. It is of great importance to have a vessel crewed to the correct levels because not doing so may result in safety and efficiency compromises (Latarche, 2013; Cordon, 2019). If not adequately crewed, vessels could be declared unseaworthy. Regulation 13 of the Safety of Life at Sea (SOLAS) convention also requires contracting governments to ensure vessels in their vessel registries are sufficiently manned (United Nations, 1980).

The basic crew composition of a merchant vessel comprises typically of officers and ratings, all under the care of the Master of the ship. These officers belong to three departments: the Deck department and the Engine room department. In the Deck department, this highest position is held by the Chief Officer. Also known as the Chief mate, the Chief officer typically has several hierarchies of officers under their care: the first, second, and sometimes third mates. In the Engine room department, the highest position is held by the Chief Engineer to whom the second and sometimes the third engineers reports.

Both departments have ratings. These are individuals who work both on the deck and in the engine room. Ratings are less skilled labour that typically carries out various duties during the voyages and the process of cargo working.

Finally, the third department is referred to as the Stewards Department. This normally consists of the Chief Cook and a Second Cook (Latarche, 2013).

1.6.3 Problems with Mariners

In recent years, some considerable research effort has been channeled towards the automation of marine systems. The research efforts have been a result of various matters including cost reduction where constraints that either reduced operational efficiencies or made it impossible for tasks to be performed existed. For example, Eich et al. (2014) worked on a robot to perform vessel inspection for areas not reachable by humans on bulk vessels. This resulted in a cheaper and faster inspection process. Huntsberger, Keegan, and Brizzolara (2010), as well as Huntsberger, Keegan, and Brizzolara (2011) list some of the recent developments in MASS research efforts. Included therein are works covering themes such as Design and Control, Adaptive Autonomy and Sensing, Hazard

Avoidance and Sensing as well as Survey and Monitoring to mention but a few. This extent of research effort coverage is testament to the clear goal that the industry has been transiting holistically from the current status quo to yet untapped possibilities promised by technological advances.

Alluded to above are that cost and operational efficiencies are the main drivers of these efforts. One of the largest cost items for a Shipowner is manning costs (Thai et al., 2013). At the same time, accidents and reduced efficiencies in ship operation are associated with the presence of the human element (Che Ishak et al., 2019). Reduced efficiencies and accidents undoubtedly impose some accountable cost to a certain maritime trade party. In this case, the cost would be attributed to the Shipowner who absorbs not only the cost of manning the vessel; except in the case of a bare-boat chartered vessel where these costs are absorbed by the charterer (Wilson, 2010); but also insurances associated with the vessel which would cover, among other things, damages to hull and machinery resulting from accidents caused.

McLellan (1997) also associates the cost of the crew to the length of the voyages, stating that the longer the voyage, the higher the costs of crewing a ship. This is associated, in part, with long periods of leave taken by crew members following one or more voyages. This is confirmed by an example made by Latarche (2013) stating that a Shipowner absorbs a cost 50% higher than the cost of tasks performed due to a mandatory leave equivalent to 50% of the period worked onboard a sea-going vessel.

Carlton (2013) associates the efficient operation of a ship not only with a well-trained crew but one that is well-motivated too. Crew training comes at a cost absorbed by the employer, who typically is the Shipowner, but may also be an agency (Latarche, 2013). Crew motivation as well, especially for crews engaged in long-voyage sea-going vessels, also comes with an employer-absorbed-cost attached to it. The costs associated with these two – exceptional training and good motivation – should undoubtedly come at a premium. An extra amount of effort by the employer to maintain these premium items is required. In fact, supporting this claim is how employers in the maritime industry adopt the Employer of Choice (EOC) strategies to attract and retain employees. As explained by Thai et al. (2013, p. 83), this EOC strategy seeks to "…continually meet the motivational, lifestyle and intrinsic needs… and attract more well-trained and developed seafarers."

Without a doubt, employees in the maritime sector bring with them a burden of cost. This burden of cost will not go away because as strategies like the EOC are widely adopted, employee turnover will only increase, thereby requiring more resources to be added to innovate further and remain competitive in the recruitment market. But, the question of whether the effort is worth it surfaces.

Employers in this industry ask themselves if there is benefit in investing heavily in these recruitment and employee retention efforts.

Another driver of the research effort is the avoidance of accidents. Although the probability of accidents resulting in a total loss of a vessel had reduced from 4% late in the 18th century to under 0.5% by the beginning of the 21st century (Stoop, 2003), accidents have remained, and still are intolerable. This is arguably largely related not only to the vast amount of capital outlay that may follow an accident, but also the inconvenience emanating from loss of productive hours, for instance.

An arrest within the maritime sector is most probably one of the main reasons accidents are to be avoided at all costs. In South Africa, a vessel, its equipment, bunkers, furniture, or even cargo within it may be arrested (AJRA, 1983, s.3(5)) if they cause accidental damages (AJRA, 1983, s.1(1)(e)) and a valid claim is instituted against them. This will without doubt cause some form of inconvenience, with the possibility of loss in productivity for the vessel to which the claim relates.

Accidents in merchant shipping are largely associated with human fatigue, lack of technical know-how, and poor or inadequate communication according to Che Ishak et al. (2019). Humans are therefore the primary focus in the combat against accident recurrence in the sector. To combat this frequent accident occurrence, training and certification in the maritime sector seem to be of utmost importance. Naturally, accidents should hardly be attributable to a lack of training in this sector because of the regulation tightness being quite high, with specific vacancies only requiring to be filled by properly certified individuals. However, Clayton (2017) suggests that the certification has no pass mark, adding that companies typically only employ people who achieve 60% or more on their training evaluations. This is certainly problematic in an environment with a declining labour supply. At some point, compromise will be taken and people who score well below the typical 60% level will enter the employment pool due to lower supply. One could argue that this is potentially already happening. The shortfall of officers only is expected to reach almost 150,000 by the middle of the third decade of this century (Clayton, 2017).

Communicating with clarity is something believed challenging to control. The supply of seafarers seems to be concentrated around Asian countries. China, India, and the Philippines are known as the major suppliers, followed by Russia and Ukraine (Clayton, 2017; Deloitte, 2011). Now, the problem here is the multi-lingual element introduced by this geographically expansive supply pool.

Finally, fatigue is something that despite measures like regular exercise being encouraged, cannot be taught out of a human body. Accidents are often caused by the unavoidable human element that is intrinsic in ship operation and navigation. Research efforts have historically attempted to model human-error-related accidents to help with investigations. The efforts then moved to help chart ways to minimize or eliminate accidents (Harald et al., 1998; Akyuz & Celik, 2014). Recently, however, research efforts exhibit a clear bias towards automation intelligence intending to eliminate humans. The work of Liu et al. (2017) is an example of this latter trend.

1.6.4 MASS (Maritime Autonomous Surface Ships)

MASS seems to be the only way forward from the Shipowners' perspective. The ultimate goal is to have no humans onboard a sea-going vessel. Research is still more biased towards systems development design and testing (E-Navigation, 2019). Regulation around MASS is also starting to emerge with the IMO having released interim guidelines for the testing of autonomous ships (IMO, 2019). However, one of the gap areas that remain understudied is the effect that this introduction of MASS will have on the employment of mariners.

MASS is a more sophisticated, and more intelligent manned or unmanned surface vessel (USV) that has various levels or degrees of autonomy, over and above mere automation. USVs in the marine industry are not new. Some of the earlier developments can be traced back to about halfway through the 20th century. The Canadian COMOX was developed in 1944, although it was never launched. Its low level of autonomy restricted it to being classified merely as a torpedo and was programmable to only move in a fixed path (Bertram, 2008). This was followed by a few decades of various United States Navy development of USV: one in 1946 for the collection of radioactive water samples; another in 1954 for minesweeping; and two others in the 1960s for missile firing practice and destroyer gunnery testing as further outlined by Bertram (2008).

Today, MASS is being developed with sophisticated systems utilizing state-of-the-art technologies that will allow them to monitor the environment in which they sail, collect data and process it into meaningful information, analyse it, and use the results to control the ships. Where applicable, some or all the information will be sent to some remote-control locations via highly capable communication systems for either human or machine control (Lloyd's Register, 2017). The remote-control centers will be located either onboard the vessel being controlled, onboard another vessel, or even on a shore-based facility. The level of manning for the cases where manning will still be required remain unclear and that is what this study will explore.

1.7 Research Methodology

To address the first part of the research question, which aims to explain existing or proposed MASS classifications, as well as which are likely to be widely adopted, the research effort will be entirely desk-based. Information will be searched for from secondary sources in the public domain, to gain an exploration of existing proposals on the various levels or categories or degrees of autonomy to be adopted by MASS. In particular, five regulatory classifications for MASS by various ICS members will be reviewed qualitatively. The selected sample of sources will be a random approach, but with the inclusion of at least the IMO instrument which is understood to be central to all. To enable comparison against each other, a standardized approach to which all instruments will be transformed will be developed. If upon analysis, some extremely varied approaches emerge, then the most likely to be adopted will be selected. The selection will be done by, for example, drawing lessons from approaches adopted by other modes of transport within the sector.

The second part of the question, which evaluates what seafarer occupations exist, and which are likely to be impacted by MASS introduction, will also largely be researched from secondary data sources developed by the maritime occupational training and certification body STCW and various other educational texts. The data collected here will be both qualitative and quantitative, describing occupations and keeping a record of their count. If necessary, lessons from other modes of transport that have successfully implemented autonomous control technology or are at advanced levels of its implementation will be drawn to arrive at a conclusive possible future for mariners.

The predominantly qualitative approach was seen as best fitting due to the novelty of this study, the predominance of written literary sources, and limited quantitative data already in existence. The technology is still in its infancy and hardly anything is, at this moment, fit to produce data that can be analysed quantitatively.

1.8 Limitations

The research work, unfortunately, takes place during the occurrence of one of the most severe global pandemics experienced in recent history; the presence of the SARS-CoV-II virus which causes a disease known as COVID-19. Among other measures taken to combat its unprecedented spread, various national governments have instituted restrictions on movement. This limits the study in two ways: First, a limitation exists with regards to accessing sources available in hardcopy prints and kept on library shelves, and second, consultation and physical visits to Ship operators and their crews are highly restricted. These would have been otherwise desired and possibly necessary to validate some of the findings. For these reasons, the study is confined to being desk-based with significant reliance on electronic sources.

Also, the population of the main data sources used is small (7) albeit the sample being big (5) relative to this population. There are a lot of classification societies that may still publish their classification documents which may result in different conclusions.

1.9 Assumptions

If growth in global trade slows down or if the main mode of inter-continental transport for global trade shifts from maritime to an alternative, the course of business in the maritime industry may be altered significantly. Consequently, appetite and attitude towards automation and autonomous shipping may justifiably diminish or become unattractive. The resulting changes in mariner employment may therefore be mostly impacted by these factors and not MASS. For the validity of this study, it is therefore assumed that:

1. Global trade:
    a. Will continue to grow as predicted by many organizations and economists worldwide including the UNCTAD (2020).
    b. Growth will not result in busier conventional ships for the same reasons outlined in section 2.5 which make shipowners want to shift to MASS

2. The main inter-continental transport industry for global trade will remain the maritime sector using maritime surface vessels.

Secondly, the adoption of MASS will very likely not be straightforward and linear. It will very likely be adopted at sporadic or possibly even volatile rates depending on various variables such as capital expenditure (CAPEX) availability, flown flags, cargo types, cargo routes, etc. For simplicity for this study, the following third assumption is made:

3. MASS adoption will be independent of, inter alia, the variables mentioned above. MASS adoption will be linear and naturally progress from least to full autonomy over time (thus resulting in autonomy saturation in the market progressing from low to high over time).

1.10 Chapter Layout

Chapter one of this dissertation will deal with the introductory information. Included therein are the background of the study, its scope and context, a brief literature review, assumptions, and the limitations of the study.

An expansive literature review will be covered in chapter two. This will cover in more detail, issues surrounding the presence of humans in sea transport. Shipowners' views and approaches to the solution of these issues will also be covered. The response of the researchers to the shipowners' approach will be discussed, covering research on MASS development and state-of-the-art in that respect. On the other hand, the extent to which the maritime sector is eyed by policymakers as a potential solution for various regional employment challenges will be explored. For this as well, the response by research bodies will be explored. Gaps will be highlighted, ultimately leading to the research approach covered in the next chapter; chapter three. Chapter three will deal with the research methodology, covering research design, data collection, and the presentation of data collected. Data collected will focus on collecting information about mariners onboard a sea-going merchant vessel. Of particular interest will be their occupations onboard a vessel looking at what each one is responsible for. The chapter will also cover issues related to their presence onboard a vessel, that somehow fuel the industry's interest in the introduction of MASS. Later in this chapter, the dissertation will switch to collecting information about MASS. Most important here will be developments in regulatory instruments aimed toward MASS. It is believed that these will form fundamental guidelines on taking MASS from design and concept phases to mainstream production and operation. Of main interest therefore will be what ship-board functions will be more likely to get automated to an extent of remote and autonomous operation. The shift in the roles of humans for various degrees of MASS automation will also be studied. All data collection will be desk-based, using publicly available electronic media which will include published books, reports, theses, academic research papers, and websites.

Chapter four will focus on the analysis of data collected in chapter three to establish the most probable future of the merchant shipping industry as far as MASS is concerned. The possible future(s) will then be used to estimate the overall impact the introduction of mass will have on mariner employment. Chapter five will present some recommendations primarily for policymakers focusing on labour and employment. It is also expected that some recommendations for the maritime law sector may be made especially if the introduction of MASS will have a drastic negative impact on mariner employment. Finally in this chapter, a presentation of the conclusion of this dissertation. Gaps for further research on matters related to this dissertation will also be outlined at this stage and in this chapter.

Chapter 2: Literature Review

2.1 Merchant Shipping

Is there any region of the world that has an abundance in thermal and coking coal reserves to satisfy its need for energy and steel manufacturing; has enough farming capability and capacity to keep its population adequately nutrified; grows enough cotton to keep everyone clothed in all weathers? If yes, then how many? Is it all regions of the world, half, a quarter, or less than a handful? These are, but a few of many commodities required by modern society to satisfy its basic needs and ensure economic growth. Fayle (1993) proposes that some regions may only have one, or two of these, but hardly any has all. Humans, irrespective of their locations, have nutritional, recreational, security, and convenience needs. The merchant marine industry brings these regions closer to each other by enabling and enhancing trade through its capacity and capability to transport in large quantities. The raw materials, fresh produce, commodities, merchandise, semi-finished goods, finished goods, and products it transports are consumed by all regions of the world and are produced in just nearly as many regions globally.

Transportation and trading in these large scales give yet another advantage: economies of scale. Cullinane and Khanna (2000), give an overview of the economies of scale associated with container shipping, which helps in making inferences about the increases in humanity's reliance on maritime transportation. These economies of scale are of extreme importance as evident in the study by Korinek and Sourdin (2009), which shows that a 100% increase in shipping costs of agricultural goods could result in a drop of as much as 42% in trade of the same goods.

To keep transportation costs low, an innumerable number of strategies are constantly adopted, one such being slow steaming for example. Slow steaming is the act of reducing speed for a merchant ship during low maritime shipping service demand. This results in less fuel consumption per nautical miles sailed, therefore reducing costs for the Shipowner or carrier. The Shipowner then shares the saving with the cargo owner in some instances. Slow steaming is not only good for the parties involved in maritime shipping by reducing costs but also for the environment, as it results in less pollution of the environment (Faber et al., 2012; Zanne, Počuča, & Bajec, 2013).

Crew reduction has also been another strategy adopted to drive costs down. This is because crew costs are among the highest expenses for a shipowner. This cost presents itself in salaries, capacity reservation on the ship, and the cost of problems caused by their presence onboard a ship (Committee on Effective Manning, 1984).

2.2 Parties in Merchant Shipping: Carriers, Shippers, Mariners, and Ports

Talley (2014) highlights 3 main players in the maritime transportation chain, namely: the carrier, the port, and the shipper. The shipper, also known as the cargo owner, is responsible for the demand side, while the supply side of the transportation services is taken care of by the carrier. The ports, among other things, facilitate or enable efficient, legal, and safe cargo handling to and fro the landside and waterside logistics.

Cargo owners need this transport chain to trade internationally in a cost-effective way. Cerit (2000) showed that exporters generally considered logistics costs as a major influence factor of their competitive advantage – with maritime transport singled out as the transport mode of choice. Munro (1999) also re-iterates this by highlighting that even for continental trade, maritime transport costs are cheaper than road-based transport. Shippers can either be exporters of goods to a buyer in another region, or they can be importers of goods from a seller in another region.

For carriers to deliver this low-cost service to the shippers, they need to run efficient vessels through an experienced and efficient crew. Vessels come in various sizes and configurations, various complexities, ages, and some are even purpose-built with dedicated instrumentation. A brief overview of these will be given in the next subsection. Crew members also emanate from various parts of the world, are trained in various institutions, and mostly can only speak English as a second language. With a diverse crew and complex ship systems, errors are likely to occur and these will be discussed in some of the next sub-sections within this chapter (Sánchez-Beaskoetxea et al., 2021).

A seaport, which is the intermediary in this trade system, is a point of call for merchant ships when they arrive at a destination to work cargo – that is, load, offload, or both. Ports are typically equipped for loading and offloading cargo, but in some instances, some of these facilities may lack, severely limiting the number, types, and sizes of ships to call them. While ports are typically owned by the local authorities as part of local infrastructure, port services may be privately owned and run. It is important for ports to be efficiently run and more adaptable to customer demands (carriers and shippers), for their competitive advantage to improve. Privatization has been identified as one of the strategies that could be applied to improve port efficiency (Tongzon & Heng, 2005; Juan, 1998).

Overall, if the shipping parties operate efficiently and at minimal cost, the case for maritime transportation as a service of choice and preference for shippers will only be strengthened. Is this therefore a case for shipping companies to move towards operating the largest ships with the smallest crew, and for port facilities to be made ever larger and more accommodating to all ship sizes with automated cargo working facilities?

2.3 Types and Sizes of Ships typical in Merchant Shipping

In 2020, according to the UNCTAD (2020b), the world's merchant ship fleet constituted Bulk carriers, Oil tankers, Container ships, and other types of vessels. From a total of just over 2,060,000 vessels, 43% were Bulk carriers, 29% were Oil tankers and 13% were Container ships – together forming three-quarters of the world fleet. These are notably the largest players and contributors in the maritime industry.

Among the minorities are General cargo vessels at 4%, Gas carriers at 3% Chemical tankers at 2%, and Cruise liners at under 1%. Below more focus is placed on the 3 largest players: Bulk, Oil, and Container vessels.

Bulk carriers deal with the transportation of homogenous commodities – typically dry ones – such as grains, rice, thermal coal, coking coal, etc. These commodities are required all over the world but are not producible as widely. Their relatively lower packing efficiency due to irregular shapes, and high demand are most likely contributors to the higher number of vessel tally proportions in the industry (ICST, 1994; Chitas, 2020).

Oil is quite commonly used across the globe as well, but only extractable in specific regions rich with crude oil reserves. It is plausible that this is the next largest category in fleet composition. Oil remains one of the major sources of energy (World Energy Data, 2021). It is used for mobility and home heating globally and is processable to various other products such as lubricating oils, bitumen for road infrastructure building (SAPREF, 2019), and other uses for example. Due to this being a liquid medium, its packing density should be a whole lot better than dry bulks, which possibly contributes to the reason this is only the second-highest contributor to merchant ship fleet globally.

Container ships have a different reason for their lower, but still growing proportion of the total fleet count. Containerships are becoming larger by size in tonne equivalent units (TEU) thus requiring less of them to carry the cargo. Research suggests that growth in container shipment is attributable to lower costs (Demir & Coşar, 2018) and quick handling at ports (Rua, 2012). I argue that it could also be attributable to several other reasons including the stackability of containers and their non-optimally used capacity from both weight and volume perspectives. Containers transport a myriad of high-value goods and are typically destined for a single customer. It is, therefore, more likely for the container to be under-utilized.

From a size perspective, the UNCTAD (2020b) reports some average deadweight tonnage ranges for these major compositions of the world fleet.

The average size range for bulk carriers starts from about 51,000 dwt for vessels more than 20 years in age to about 85,000 dwt for those under 4 years of age. The largest bulk carrier known at the time of this research project was a very large ore carrier (VLOC) of 400 dwt (Zeymarine, 2020).

For the oil carriers, the average size range – the gap between the smallest and the largest – is the largest of the 3, starting from just about 10,000 dwt for vessels older than 20 years of age, to some 93,000 dwt for vessels younger than 4 years in age. The smaller vessels could be attributable to offshore crude extraction rigs being in close proximities to the shore-based refineries or processing facilities. The largest trading oil tankers found at the time of this research were the TI class ultra-large crude carriers (ULCC) each with a size of some 234,000 dwt (VesselTracking, 2021).

Container ships on the other hand have an average size ranging from 20,000 dwt for vessels older than 20 years in age, up to some 80,000 dwt for those under the age of 4. At the time of this research being conducted, the largest containership had a capacity of just under 24,000 TEU (Chambers, 2021) and some 228,000 dwt (MarineTraffic, 2021). These parameters qualify this ship to be classified as a ULCS – an ultra-large container ship.

The next question that immediately comes up is what size crew would such large vessels require to be run efficiently? The current day’s largest VLOC requires 22 crew members (MaritimeCyprus, 2020), but is this number representative of the industry?

2.4 Merchant Ship Crew: Overview, Supply, and Demand

Manning a ship is regulated. This is to ensure safety at sea by ensuring each crew member has enough time to rest and none is overworked. Most jurisdictions base their regulations on chapter 5 of the Safety of Life at Sea (SOLAS) instrument by the IMO (IMO, 2019b; Lloyd's Register, 2005), an action that is fervently welcome due to the international nature of the maritime sector – see sub-section 2.5. Regulation 14 of the SOLAS, for example, includes regulation of the language to be used on the ship, the deck, and between the deck and the pilots.

These manning regulations are without doubt beneficial to everything and everyone involved in the merchant shipping industry: the safety of the vessel and its crew for the carrier, the safety of the cargo and its efficient working and haulage from source to destination for the cargo owner, and the safe and efficient port usage for the port owners and port service providers. However, these regulations pose apparent challenges in finding or recruiting the crew, primarily.

The US Maritime Administration source quoted by the Committee of Effective Manning (1984) showed that the US vessel crews had decreased from about 45 mariners per vessel in the 1950s to about 21 to 23 mariners per vessel by the early 1980s. For European and Japanese advanced ships at the time, the crew averaged about 21, with the minimum being 16 on a Roll-on/Roll-off (RoRo) ship. The maximum size of the ships quoted here was a mere 63,000 dwt modern dry bulker. Deloitte (2011) established through a survey that most ships required a crew size of between 20 and 25 members. Notably, Liquefied Natural and/or Petroleum Gas carriers could go as low as 15 crew members, but the rest, which included Handy bulk and reefer vessels, Panamax vessels, Aframax vessels, Suezmax, and VLCC all required at least 20 crew members, and could go as high as 26. The size ranges for these vessels can be as follows: Handy can be up to 39,999 dwt; the Panamax ranges from 65,000 to 99,000 dwt; the Aframax can range from 85,000 to 124,999 dwt; the Suezmax up to 199,999 from 125,000 dwt and finally, a VLCC covers the range 200,000 dwt to 319,999 dwt UNCTAD (2020b).

What is clear from this is that over time, the crew size seems to have stabilized at around 20 mariners on average, but the ship sizes have continued growing – especially container ships.

75% (about 1,500,000) of the world's fleet composes of these size vessels and larger (UNCTAD, 2020b). These vessels require crew sizes of between 20 to 26 members per vessel. The level of deployment and utilization of the world fleet size above is not clear from the report. However, if 100% deployment and utilization were to be assumed, then between 30,000,000 and 39,000,000 mariners would be required if only one crew per vessel was to be appointed. This is a massive potential employment quantum. However, some of these vessels, especially long-voyage sea-going vessels, need more than one crew allocated to them to allow crew rotation, as opposed to short-voyage coastal vessels. Therefore, expanding the implied potential employment numbers above by a factor between 1 and 2 gives an idea of the even bigger magnitude in employment potential and capability the industry has at the moment. We learn, however, from an estimation by BIMCO, that only about 70,000 vessels were in operation in 2021, with total estimated employment of 1,87 million mariners (Srinivasan, 2021). These numbers are a far cry from the potential numbers above and suggest low utilization of the current fleet.

Two questions immediately arise with the knowledge gathered thus far. The first is whether enough education and training capacity exists to continuously feed the maritime sector with qualified mariners, should business and demand grow enough to require the current global fleet to be fully utilized. The second is whether this magnitude of employment potential or capacity is already attracting the attention of those responsible for creating an environment for employment creation.

The latter question will be dealt with in 2.6, but as far as training and supply of mariners are concerned, the main sources are the Philippines and India. While the former is second to none in the provision of both officers and ratings in the regions surveyed by Deloitte (2011), the latter seems to struggle to provide any ratings in the European region. The report proceeds to explain the reasons for this dominance in mariner production as being linked to a good command of the English language and the limitation of other employment opportunities in both countries. Overall, evident in the report is that Asian countries provide most seafarers in the world.

One might ask, however, why bother with the training of mariners to begin with? Well, the global organization IMO has several instruments which contain various requirements to be met by sea-going vessels for its contracting nations. One of the regulations is the Efficient Manning Requirements and in the next sub-section, this topic is explored.

2.5 Efficient Manning Requirements

The SOLAS Convention is an international treaty governing the safety of life at sea. It achieves this by prescribing minimum design and operation requirements for vessels and their equipment in 14 chapters. Contracting nations must ensure that all vessels flagged under them comply with these requirements, and under certain circumstances, and are empowered to inspect vessels flagging other contracting nations (IMO, 2019b).

Regulation 13 of the SOLAS convention sets out the requirement for sufficient and effective manning for national ships by contracting nations. The guidelines for these requirements are set out in Resolution A.1047(27) titled *Principles of Safe Manning*, and its objectives, among others, include the insurance that (IMO, 2011, pp. 1, Annex 1, Point 2):

> *"a ship is sufficiently, effectively, and efficiently manned to provide safety and security of the ship, safe navigation and operations at sea, safe operations in port, prevention of human injury or loss of life…"*

The resolution then states that when determining the minimum safe manning for a vessel, the following considerations should be taken (IMO, 2011, pp. 3, Annex 2, Point 1.4):

> *".1 the number of qualified and other personnel required to meet peak workload situations and conditions, with due regard to the number of hours of shipboard duties and rest periods assigned to seafarers; and*
> *.2 the capability of the master and the ship's complement to coordinate the activities necessary for the safe operation and for the security of the ship and for the protection of the marine environment."*

From the above, the importance of crew size, the crew members' qualifications, and their abilities to perform their responsibilities at peak periods preceded and followed by enough rest could not be more apparent.

The Standards of Training and Certification on Watchkeeping (STCW) is the instrument designed to deal with the qualification element. It governs and guides the training and certification of mariners that should be adhered to (IMO, 2019c).

Various contracting nations are not ignoring these SOLAS requirements. South Africa, as an example, has integrated this into its local laws. Parts 3, 4, 6, and 7 of the Merchant Shipping (Safe Manning, Training and Certification) Regulations, 2021 deal with Certification, Training, Manning Requirements, and General Manning Levels for ships (DoT, 2021).

However, is this enough? Does it fully foolproof the system and industry against human error, and does it promise optimum human efficiency? Well, it seems not, as there are widely reported issues arising from the human element onboard a vessel as explored in sub-section 1.2 above and continues in subsection 2.5 below.

2.5 Issues related to the presence of mariners for a shipping company

Common amongst all seafarers irrespective of their line of duty onboard a vessel are the problems of sleep and fatigue. This was a finding by Hystad and Eid (2016), stating prolonged durations of time at sea and the lack of separation between working and leisure environments, which are otherwise confined spaces, as the reasons for the problems. It is only reasonable to expect errors and mistakes from individuals experiencing such problems in their work environments. In existence, however, are also departmental or occupational challenges that vessel staff experience.

2.5.1 The Deck Department

A study of maritime accidents emanating from countries in Australasia, Europe, and the USA between 2002 and 2016 revealed quite several sources somewhat linked to the Deck Department. Inadequate lookout, Poor judgment, Rule violation, and Unsafe speed featured 24.6%, 14.1%, 7.3%, and 5.6% respectively as immediate causes of collision, close quarters, and contact accidents (Acejo et al., 2018). The total for these four is 51.6% and they all seem to be attributable fully to the Master and Deck officers. Together, they featured a total of 26.2% – just over a quarter – of the reasons ships got involved in grounding accidents. Most of the other reasons stated by Acejo et al. (2018) are not necessarily exclusive of the deck department personnel, but it cannot be established to what extent they were involved. It is not clear, for example, who to attribute poor communication or ineffective use of technology in a vessel to. It could be from any of the 3 departments of a ship's organization. It is therefore clear that the problems associated with the deck department in this study could be higher.

2.5.2 The Engine Department

Lundh, Rydstedt and Dahlman (2011) highlight some of the most prevalent issues in the engine room for the crew members who work there. The issues include unfavourable temperatures, awkward postures, and high levels of noise. These authors report that these conditions often lead persons to devise alternative ways of performing tasks that may otherwise not be safe for them. Islam et al. (2018) developed a model to predict the probability of human error while performing maintenance activities by both the engine room departments and the deck department.

It is not unreasonable to expect that such less than optimal and less than adequately ergonomic conditions will not only endanger the engine room staff's health and lives but will also affect the quality of their work. Accidents in the engine room may result. Less than optimal operation of the engine room equipment may also result which in turn may affect the efficiency of the ship. Mistakes may lead to the ship causing accidents. Consequently, insurance costs and other operational costs such as fuel costs for a journey may increase.

Acejo et al. (2018) quote only one reason as an immediate cause of collisions, close quarters, and contact accidents that can be directly attributed to the engine department: inappropriate/ineffective maintenance. It only features 1.2% as a cause for this category of accidents and does not feature at all as a cause for grounding accidents. This is quite remarkable, but the same cannot be said for the other two types of accidents included in the report. Inappropriate/ineffective maintenance features some 16.7% of the time as a cause for fire and explosion accidents in vessels and a massive 26.1% as a cause for lifeboat accidents. Also, to attract such a group of staff onboard a vessel, the shipowner may have to offer higher compensation, and possibly cover more costly medical insurance to cover these heightened hazards. The alternative for the shipowner may be to provide extra systems to neutralize these issues. These may include ventilation systems, more expansive working areas, or even some more expensive equipment requiring less maintenance.

2.6 Employment Creation Potential of the Maritime Sector

Smith-Godfrey (2016) in his work on defining the Blue Economy, identifies five value chain levels. Two things that can be noted here are: (i) All five of them, some to a larger extent than others, require transportation of either people or goods into the sea and/or back, and (ii) The fourth level is directly about growth in merchant shipping transportation services as we know them today. A cursory look seems to suggest that the demand for seafarers is expected to increase as workers, tourists, explorers, and researchers get frequently ferried to and back from the sea. This will be, of course, up until humans start to establish permanent residences next to these new sea-based places of employment, business, and studies: for history tells us they will.

Policymakers are duly aware of the potential the Blue Economy brings from an employment creation perspective. Without a doubt, the Blue Economy will bring new jobs – some the same as existing ones from known shore-based industries but adopted for off-shore environments, while others will be completely newly created.

To mention a few, Operation Phakisa in South Africa identifies the Blue Economy as a source of new employment in various sectors. Operation Phakisa's Blue Economy will have 6 workstreams. At least 4 of the 6 workstreams that it targets under this program will require sea-going vessels (GCIS, 2021; DFFE, n.d.).

The first one of the six – Maritime Transport and Manufacturing workstream – aims partially directly at seafarer employment and partially at shore-based manufacturing activities. The second, third, and sixth workstreams – Offshore Oil and Gas Exploration, Aquaculture and Coastal, and Maritime tourism respectively – are also not directly aimed at mariner jobs, but they will be created in the process. In these four cases as well, various mariner occupations will benefit differently in each workstream. For example, in Tourism, the Stewards departments will benefit more while in Oil and Gas Exploration, Engineer's departments may benefit more.

The South African government has gone to fund numerous educational activities in formal education institutions towards cadetship programs, all in preparation for taking advantage of the benefits the Blue Economy or the Ocean Economy promises. Some R296 million was reported to have been set aside for this, and 25 new qualifications were to be developed and taught in various institutions of higher education and training (DFFE, n.d.).

The Organization for Economic Co-operation and Development (OECD) also acknowledges the potential for the ocean to help meet some of the increased needs for employment, food, energy, and raw materials to support economic growth. It refers to Ocean-based industries and categorizes them into two broad categories: Established and Emerging industries. Under the former, it lists, for example, Capture fisheries, Shipping, Dredging, and Maritime and coastal tourism; while under the latter, it lists Deep and Ultra-deep water oil and gas exploration, Offshore wind and Ocean renewable energy, as well as Marine and seabed mining (OECD, 2016). All of these can be reasonably expected to require ferrying of persons to and from these new ocean-based places of employment. This is evidence that among the jobs to be created, the OECD also expects higher mariner demand and employment opportunities.

The UNCTAD has also emphasized the need to assist Developing Economies to put together strategies for their Oceans Economies. The UNCTAD has done this through its Oceans Economy and Trade Strategy (OETS) program. An example of a developing country already in the program is Belize which has, among its targeted sectors, the Marine fisheries (UNCTAD, 2020c). Other jurisdictions benefiting from this program are Costa Rica (UNCTAD, 2019), Barbados (UNCTAD, 2020d), and India (UNCTAD, 2021). It is not unreasonable to expect that a mariner employment increase is among the targeted success measures for his program.

With the imminent implementation of MASS, however, should the prospects of higher mariner demand be reconsidered?

2.7 Port Services and Interaction with Vessel Crew

Ports provide services to both shipping companies (carriers) and shippers (cargo owners) alike. When shipping companies call a port, they need various services such as Vessel tracking Services (VTS), Pilotage, Tugging, Ship repair or Engineering Services, and Cargo working. Traditionally, most of the above-mentioned services involve human-to-human communication and, or interaction. For example, pilots approach and board the incoming vessel either through a boat or via a Helicopter; join the crew of the ship, and help with port approach while navigating to the desired location like a berth or turning chamber (Weigall, 2006; Park, Yip, & Park, 2019). However, a study in Europe revealed that there were cases in which shore-based pilotage was done, and pilots were relatively dissatisfied with that arrangement (RH & H Consult, 1995). Although shore-based, it is worth highlighting here that Pilotage was still a human-to-human interaction, with at least one of the parties onboard the vessel – that is, the captain. The question is just how disruptive would MASS introduction be to the Pilotage process? Would it completely eradicate the need for pilots onboard a vessel? If the pilotage is not completely eradicated, the question that remains still is whether it will still be required for every entry made into the ports by a qualifying ship, or will pilotage only be needed in the case of incidents and/or near misses? In other words, would a pilot be required for a highly intelligent, fully autonomous ship with the best detection and computing technologies? Would the involvement of a pilot not be a backward movement by re-introducing the human element in the system, leaving it ever more prone to mistakes and accidents?

Coverage on the interaction between VTS and MASS seems to have already started. Chyuan (2018) covered this aspect, producing a series of recommendations to VTS operators in preparation for dealing with MASS, the most interesting being VTS to be located next to the RCC to facilitate communication during an incident. In general, no major concern is noticeable over cargo working on a fully autonomous surface ship – so long as everything is working to order. The main question arises when problems start to emerge, resulting, for example in delays. If some parts of the ship's cargo-holds malfunction, how do inspections and expeditious decision-making take place? Is the introduction of MASS potentially going to create new job opportunities in this regard? In other words, could there suddenly be a need for a shipping company's representative to monitor the process of cargo working and assume the responsibilities of inspecting and expeditiously getting to a solution – whether by feeding back to the owners or taking decisions on their behalf?

The next chapter will deal with the methodology employed to collect data. The chapter will deal with how the methodology was executed, and present the data collected. In addition, and in preparation for the chapter that follows – The analysis chapter – this data will be manipulated to a standardized format to enable cross-comparison.

2.8 Maritime Autonomous Surface Ships (MASS)

MASS is an emergent technology within the maritime sector, probably better describable as a strategic one, that will see the conventionally crewed vessel advance from being heavily human-dependent to being less so, and ultimately to an extent of zero-human-dependence for its commercial operation. Backing this view is a multitude of activities spanning research, development, trials, and classification of these vessels as will be discussed next.

2.8.1 Description of MASS

MASS is described by the IMO as *"…a ship which, to a varying degree, can operate independently of human interaction"* (IMO, 2018a).

2.8.2 Research, Development, and state of the Art

Globally, various topics around MASS are concurrently being researched by scholars. Topics of interest revolve around safety and collision avoidance. For example, Nangung and Joo-Sung (2021) propose a COLREG-compliant collision risk interference system for MASS, while Jing, Shen, and Yin (2020) propose six-degrees-of-freedom motion simulation and modeling MASS under true environmental disturbance. The former is necessary for MASS to avoid damage to itself by other objects and vice-versa, while the latter focuses on MASS being capable of ensuring its safety while at sea and subjected to 6 degrees of freedom. While these activities are currently mostly left to humans to assess and react appropriately for today's non-autonomous ship, with MASS, a possibility exists that there will be limited to no humans on board to assess the situation and adequately apply corrective measures. MASS will need to have enough intelligence to initiate proper protection measures.

In outlining the various systems of MASS – Ground Station, Communications System, Data Collection System, Propulsion and Power System, Hull and the Guidance, Navigation & Control (GNC) System – Wang et. Al (2019) highlighted the GNC system as being "*core to motion control*" as well as being "*key to the safe and autonomous navigation of the ship*". Finally, and in my view most importantly, these authors proposed that the core of the intellectualization of MASS is to "*is to enable ships to have the ability to observe, think and deal with problems as human beings*" (Wang, Wu, Liu, Li, & Negenborn, 2019, p. 5 par. 1).

Development and Trials of some of these systems (or even complete Ships) are also currently underway in various jurisdictions. A Rolls-Royce and a ferry operator in Finland successfully operated a fully autonomous ferry as early as 2018 (Rolls Royce, 2018). In the year 2019, the Japanese NYK Group conducted a trial on an autonomous navigation system called the Sherpa

System for Real ship (SSR). Extremely remarkable about this test was that it was not performed in a laboratory or simulation setup, but over a full coastal journey from Xinsha, China to Yokohama, Japan via Nagoya, Japan. The system was tested on a real 70,000 dwt vessel, in real coastal sea conditions over many days, calling multiple ports (NYK, 2019).

What can be deducted here is that safety is of great importance and MASS has to replicate the actions traditionally performed by humans to deliver the same, or better safety levels. Humans, however, follow regulations, and most legislation is written with them involved in ship navigation. MASS, therefore, brings with it a unique challenge in terms of regulation and legislation – especially if it is going to be expected to make decisions on its own. Below, some of these challenges are discussed.

2.8.3 Challenges expected with MASS: Legislative and Ethical Artificial Intelligence

Also prominent in the MASS scholarly works, albeit not to the same extent as safety discussed in the preceding sub-section, is the study of the legislative shift required with MASS development and introduction to the market. It is argued by scholarly works that most IMO instruments will have to be modified to accommodate MASS.

The SAFEMASS study was commissioned by the European Maritime Safety Agency (EMSA) to identify risks and regulatory issues with specific levels of MASS autonomy levels. For a specific chosen case (specific MASS Autonomy level), it was identified that three IMO instruments would need modification for MASS to be introduced, namely: COLREGs, STCW, and SOLAS conventions (Øie, Erlend, Johnsrud, & Lindberg, 2020). The study highlight, within these instruments, issues related to Manning, Responsibility, Lookout, and Watch-Keeping for a merchant vessel.

Commissioned in the year 2017 by the IMO, the Regulatory Scoping Exercise (RSE) was concluded and a report was published in 2021. It aimed to "*determine how safe, secure and environmentally sound MASS operations might be addressed in IMO instruments*" (IMO MSC, 2021, p. 3 point 3). Included in the published report are all the IMO instruments expected to be affected by MASS operation for every degree of autonomy. The prioritization of future work to address all issues, as well as the order in which these instruments are to be addressed is also included in the report. Of absolute high priority and requiring urgent attention were four things, namely: Meaning of the terms master, crew, and responsible person; Remote control station or Remote control center; Remote seafarer or operator; and Terminology (IMO MSC, 2021).

Meanwhile, a fully autonomous ship with the capability to make decisions and effect changes attracts challenges of its own – those of Ethical Artificial Intelligence (AI). In a book-length article, Hibbard (2015) proposes that future AI will be different from the current. He proposes this based on the idea that future AI will operate with learned models whose complexity far exceeds models created by humans, as is the case for today's AI systems; and that they will very likely be able to avoid unintended action or consequences. These unintended actions or consequences are central to ethical AI. This author's proposal brings some form of comfort in a world that is understandably concerned about AI and ethics. Meanwhile, aimed at encouraging human-centered and ethical AI development, there was an adoption of the Recommendation on the Ethics of Artificial Intelligence (REAI) by United Nations Educational, Scientific and Cultural Organizations (UNESCO) members at its 41st session (UNESCO, 2021). Until Hibbard's (2015) proposals start being realized, the REAI adopted by UNESCO members will very likely influence activities around Artificial Intelligence in MASS development.

2.9 Automation Impact on Labour Force

Automation in general is geared towards reducing or even eliminating a burden on the human factor. It is claimed, by authors Oschinski and Wyonch (2017), that automation increases productivity, and if an increase in the demand for a supplied product or rendered services does not escalate, then the likelihood of decreased employment opportunities is almost certain. They add that decision on whether to automate or not depends on the size of the business, its competitive landscape as well as the perceived benefit from replacing labour with machinery from a cost perspective.

In this respect, the following questions can be asked for merchant shipping: Could automation increase at a pace that outstrips the growth in global demand for shipment services? And an even bigger question is whether the cost would be worthwhile.

Drewry (2019) is quoted by world maritime news emphasizing the importance of economic benefits of automation before a decrease in seafarer employment can be seen in the medium term. What this author seems to agree with is that an impact on mariner employment is inevitable.

Chapter 3: Research Methodology

3.1 Introduction

This chapter deals with the research methodology of this dissertation and how it was executed. The chapter presents three sub-sections: the first deals with data collection design; the second deals with the results of MASS data collection efforts; and the third with the results of Mariner occupation data collection efforts. The second subsection also includes the re-arrangement or manipulation of data in preparation for comparative analyses in the subsequent chapter to this.

3.2 Data Collection Design

The type of problems being dealt with here required the researcher to undertake an in-depth exploration of the status quo of MASS research and development, as well as an in-depth exploration of the current occupations for mariners.

3.2.1 Qualitative Analysis and Analysis Technique

Onwuegbuzie et al. (2012) list four major types of sources that qualitative analysis is befitting, namely: *Talk*, *Observations*, *Images* (still and motion), and *Documents*. Warren (2020) defines qualitative data as anything that is not numbers and cannot be measured or put on a scale for complex statistical or mathematical analysis. Qualitative analysis, therefore, is a method fitting the type of data, and sources that will be analyzed in this research work, because texts in documents will be analyzed.

Many techniques of qualitative data analysis have been written about and used widely. While Warren (2020) identifies the following 6 as being the most used: *Qualitative content analysis*, *Narrative Analysis*, *Discourse Analysis*, *Thematic Analysis*, *Grounded Theory Analysis*, and *Interpretive phenomenological analysis*; Onwuegbuzie et. al (2012) identify as many as 17 different techniques that can be used.

Qualitative content analysis and Thematic analysis sound somewhat fitting to the research work at hand. Qualitative content analysis is also known simply as Content analysis, and Harwood and Gary (2003) describe it as a method of analyzing a variety of data content, including but not limited to visual and verbal data. It has been hailed as potentially a researcher's most powerful tool, especially in the era of big data analytics owing to its great versatility (Stemler, 2015). These authors add that it can reduce events into categories for better analysis, further highlighting that it has the potential to be used in education and criminology.

Neuendorf (2018) reports that content analysis typically takes the form of deductive analysis – which is a form of analysis that starts with the theory and attempts to arrive at confirmation of fulfillment of that theory.

Thematic analysis, on the other hand, can be used in the analysis by extracting themes and patterns out of code clusters or domains. It is argued that it is quite widely used in psychology, while possibly not adequately acknowledged. It can be used to analyze large texts using codes and themes. Braun and Clark have proposed steps to complete that goal effectively and efficiently (Braun & Clarke, 2006; Onwuegbuzie et al., 2012).

This research, however, seeks to establish a theory on mariner employment inductively by drawing an inference from the analysis of existing documentary sources. For this reason, the Thematic analysis technique will be employed in this research work.

3.2.2 Data Sampling Technique

The novelty of the MASS technology leaves only a handful of reliable sources to extract data from. After a rigorous research exercise, it was discovered that available are scholarly works on MASS, Project or Prototype ships by various organizations, and MASS development guiding and classification documents by classification societies. From these 3 possible sources, it was decided that the latter would be the main source of data for this research work. The decision was firstly due to these sources' broad and structured approach to presenting data on MASS as opposed to scholarly works, which can be too specific leaving massive and numerous gaps for extrapolation; and secondly due to the public accessibility of these sources as opposed to project boats which companies withhold data for presumably to safeguard intellectual property.

The data to be collected for both analysis activities stated in the introductory paragraph of this section – section 3.1 – is publicly available and presents itself in various documents. From a population of seven classification and guidance documents published by the members of the International Association of Classification Societies (IACS) listed in Appendix A1, a sample of 4 was randomly selected. Before the random selection, however, one instrument – the IMO MASS classification instrument – was isolated and chosen to be part of what would be five instruments or documents to be used. This was done because of the central position that the IMO assumes in all matters maritime. The IMO is often a reference for developing new policies, procedures, rules, and regulations in the maritime industry by various jurisdictions (Blanco-Bazán, 1992).

From the remaining six instruments (IMO removed), a random selection of four (66%) was done through the employment of Microsoft Excel's built-in RANDARRAY function (see Appendix A2 for results). With six sources to choose from, it was decided that a six-row, six-column array would result in a satisfactory amount of randomization. The sources were placed along the rows (forming six rows) and random number generation iterations, ranging between 1 and 100, were generated six times per source. The results for each of the six randomizations were listed in columns to the right of each instrument (See columns “R1” to “R6” in Appendix A2). For ranking to be possible to eventually select four instruments, an average of the random numbers “R1” to “R6” was calculated for each instrument. These averages and rankings can be seen in the columns titled “Avg Rx” and “Rank” for each instrument’s random numbers and ranking respectively. The four lowest ranking instruments were then selected as the ones to join the IMO instrument for analysis.

The analysis approach used for each of the five selected MASS classification instruments was Thematic Analysis. The themes used were a result of various codes picked up while going through, initially, the literature reviews, and then the classification instruments.

The initial themes resulting from the codes used were *Information Acquisition, Information Analysis, Action Initiation, Decision Making, Monitoring & Control,* and *Location of Humans*. However, Monitoring & Control were later split to *Monitoring* and *Control,* as it became better understood that one could happen without the other. The themes then changed from six to seven. Finally, *Location of Humans* changed to *Compulsory on-board manning,* as it became clear that humans could be on board maintenance activities for example.

These themes were then used in transposing the classification instruments to a standardized format to facilitate cross-comparison.

The standardized representation of the regulatory instruments is done by listing the themes along the columns. Six of the seven themes or columns represent functions in a ship that can be performed by ships systems, by mariners, or both. The seventh theme contains an indication of the need for humans to be permanently onboard vessels per level or degree of autonomy. Along the rows, the number of degrees of autonomy by each instrument will be listed. “H”, “S”, “M/S”, and “-(hyphen)”, will be used to indicate Humans, Ship’s System, a combination of both or neither respectively.

For the mariner occupation part of the study, any credible source containing information about seafarer occupations was used. The STCW documentation was used to the extent beneficial but augmented with content from other credible literature sources. No analysis technique was necessary for this section. These are well-defined roles that the reader is meant to be made aware of. This section is therefore merely a compilation of data to familiarize the reader with mariner occupations

3.3 Collected data on MASS

To explore firstly what levels or degrees of autonomy are likely to be adopted for MASS in the maritime sector, it is necessary to find out what is front of mind for various role players. There must be matters they aim at including, excluding, expanding, shrinking, being cautious of, etc. Role players in cases like this may include shipbuilders, shipowners, maritime labour brokers, cargo owners, port owners, port operators, port services providers, environmental protection officials, legislative bodies, policymakers, etc. As evident here, the number of legible role players and contributors can be quite extensive, and one can never be fully certain all parties have been approached and included if primary data were to be collected.

This research, therefore, benefits from efforts already taken by various bodies – Classification Societies – which have published various documents. The documents are regulatory, classification, and guiding literary instruments aimed toward assisting interested parties and regulating various matters in the journey towards the introduction of MASS.

This subsection mines data on MASS from a selected few of these regulatory, classification, and guiding literary instruments in preparation for an in-depth analysis in the next chapter – Chapter 4.

MASS is expected to assume different levels of autonomy which will range from low to high degrees of autonomy. On the one extreme, low-autonomy degree ships will be closest to conventional ships known today equipped with only a few automated systems from an automation perspective, but with none to extremely limited cognitive and learning capabilities. On the other extreme, high-autonomy ships will be so sophisticated that they will set sail unmanned, interacting with the environment, learning as they do so, and becoming more adaptive to their surroundings. These ships will be backed by Artificial Intelligence. To achieve this range of autonomy, the existing trend of ship systems becoming automated will need to continue, perhaps even accelerate, while the budding trend of making ship systems smart – that is, capable of learning and adapting to their environment – will need to become more entrenched. Human involvement in ship operation or running will diminish as the degree of autonomy increases, leading to a state where they (humans or mariners) may no longer be required. This terminal state aimed toward is fully autonomous, artificially intelligent ships.

If mariners are ever needed, it will be very likely for the monitoring and maintenance of the ship either from within the vessel itself or merely reacting to prompts for such activities from a remote location.

Five classification and guiding documents were used to collect data on what can be expected for MASS. These instruments include *Guidelines for Autonomous Shipping* by Bureau Veritas (2019), *Cyber-enabled ships: ShipRight procedure assignment for cyber descriptive notes for autonomous & remote access ships* by Lloyd's Register (2017), *Maritime Autonomous Ship Systems (MASS$_{UK}$) UK Industry Conduct Principles, and Code of Practice* by Maritime UK (2021), *Definitions for Autonomous Merchant Ships* by NFAS – Norwegian Forum for Autonomous Ships (2017), and *Maritime Safety Committee Degrees of MASS Autonomy* by IMO MSC 100 (2018b).

In these classification and guiding documents, the information sought can be categorized into three broad categories:

- The levels or degrees of autonomy that can be expected for MASS
- The ship systems and, or functions that are expected to gain autonomy
- The levels of involvement that humans (mariners) are expected to have

It is therefore of great interest to explore each of these instruments, one at a time for their approaches to MASS for each of these broad categories. Ultimately, the goal is to compare these instruments against each other and establish where commonalities or convergences lie, as well as where differences or divergences lie. Convergences will be taken as signifiers of what is most likely to happen in the future, while divergences will be understood as what may take longer if at all, to become reality.

To compare these instruments and check for both convergence and divergence, a standardized format will be required. This is due to the varying quantities of degrees of autonomy assumed by each instrument. Some instruments have as few as four degrees of autonomy, while others have as many as six. How they describe their degrees of autonomy also differs significantly, but ultimately, they point to whether the system (S), a human being (H), or both (H/S) will be performing a given function.

The standardized representation using the standardized format (see Table 1) will be in this chapter. This standardized representation will borrow most features from the Bureau Veritas guiding document (see Table 2). However, for each instrument, including Bureau Veritas', the original data in its original format will be explored before transposing it to the standardized format. From Table 2 (Bureau Veritas regulatory instrument) therefore, the following columns are borrowed for use in the standardized format:

- Information Acquisition
- Information Analysis
- Action Initiation
- Deciding Authority

In addition to these, the following will be added to complete the standardized format:

- Control
- Monitoring
- Compulsory On-board Manning

The skeleton of the standardized format will therefore be as presented in Table 1 below.

Table 1: Skeleton of the Standardized format for Degrees of Autonomy

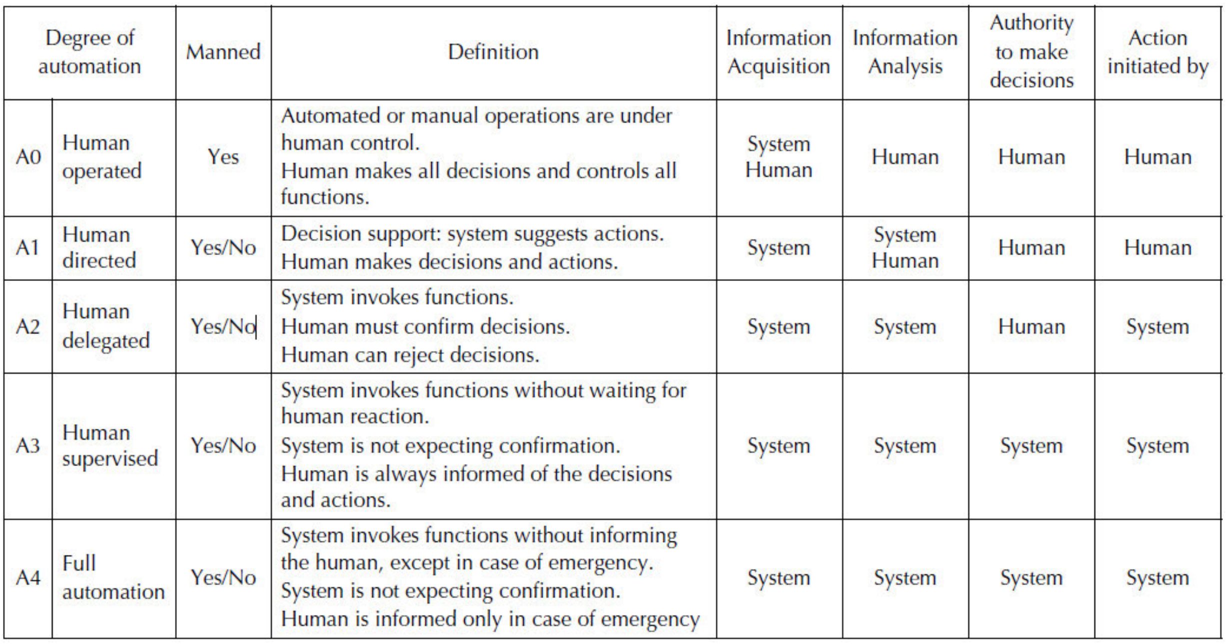
0	1	2	3	4	5	6	7
Autonomy / Automation Degree	**Information Acquisition**	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
Code 1							
Code 2							
Code …							
Code *n-1*							
Code *n*							

3.3.1 Instrument 1: Guidelines for Autonomous Shipping *(Bureau Veritas, 2019)*

Concerned about potential new hazards and risks to be introduced by more reliance on information and communication technology as enablers in shipping industry automation, Bureau Veritas saw it necessary to publish some guidelines. The guidelines are for usage by designers and builders for various automated ship systems, which will be employed in autonomous ships.

In the guidelines, some five degrees of automation are defined. These degrees of automation range from A0 to A4: the lowest ranking has the least automation and highest reliance on humans, while the highest ranking has the least reliance on humans due to a higher number of automated capabilities. Table 2 below shows these degrees in more detail.

Table 2: Degree of Automation (Bureau Veritas, 2019, p. 10)



Degree of automation		Manned	Definition	Information Acquisition	Information Analysis	Authority to make decisions	Action initiated by
A0	Human operated	Yes	Automated or manual operations are under human control. Human makes all decisions and controls all functions.	System Human	Human	Human	Human
A1	Human directed	Yes/No	Decision support: system suggests actions. Human makes decisions and actions.	System	System Human	Human	Human
A2	Human delegated	Yes/No	System invokes functions. Human must confirm decisions. Human can reject decisions.	System	System	Human	System
A3	Human supervised	Yes/No	System invokes functions without waiting for human reaction. System is not expecting confirmation. Human is always informed of the decisions and actions.	System	System	System	System
A4	Full automation	Yes/No	System invokes functions without informing the human, except in case of emergency. System is not expecting confirmation. Human is informed only in case of emergency	System	System	System	System

For the lowest degree of automation – A0: Human Operated – the vessel is equipped with systems capable of information acquisition only. This activity, however, is not solely left to the vessel's systems; humans assume the role of information acquisition, but also perform the analysis of the information gathered, which the systems are incapable of doing. The vessel remains dependent on human beings located onboard the vessel for information analysis, decision making, and initiation of various actions.

For the next degree of automation – A1: Human Directed – the acquisition of information can be solely left to the vessel's systems. The reason for this is the existence of a possibility for the humans to be periodically absent from the bridge or be completely absent from the vessel. For this reason, the vessel will have to be equipped with devices such as sensors, and cameras for constant information acquisition. The ship is also equipped with systems that can analyze the acquired information – an activity shared with humans – and make suggestions for actions to be taken or considered. However, making decisions and taking appropriate action is still left solely to the humans, who may be located either onboard the vessel, or at an RCC located away from the vessel concerned.

Degree of automation *A2: Human Delegated* is even more automated: It is not only equipped with systems of information acquisition and analysis, but it has the capability to recommend decisions and to initiate action. What is left for humans is taking the ultimate decision and authorizing or declining the system-initiated actions. The humans may do this from either onboard the vessel or an RCC.

The main difference between the second to last and last degrees of automation *A3: Human Supervised* and *A4: Full Automation* respectively are the need for the vessel's systems to inform humans of the decisions taken. For the former automation level, humans are always notified of the decisions taken while for the latter, only in the cases of emergency are humans informed. In both cases, the ship-board systems acquire information, analyse it, make decisions, and take actions. It is possible for humans to be onboard the ship or be located at an RCC. Humans can override any decision taken by the systems at any time.

Table 3 below represents the Bureau Veritas degrees of automation in the standardized format.

Table 3: Standardized Bureau Veritas representation of the Autonomy Degrees

0	1	2	3	4	5	6	7
Autonomy / Automation Degree	**Information Acquisition**	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
A0	**S/H**	**H**	**H**	**H**	**H**	**H**	**H**
A1	**S**	**S/H**	**H**	**H**	**H**	**H**	**S**
A2	**S**	**S**	**S**	**H**	**S/H**	**H**	**S**
A3	**S**	**S**	**S**	**S**	**S**	**S/H**	**S**
A4	**S**	**S**	**S**	**S**	**S**	**S**	**S**

In Table 3, the first four columns have already been discussed in detail in the prevailing subsection. Control of the ship, as can be seen in column 5, is understood as being completely under the control of human beings for degrees of automation A0 and A1. Control of the vessel is, however, shared between the humans and the vessel’s systems for degree A2. The vessel is completely under the control of its systems for degrees A3 and A4 under normal conditions. It should be noted that human beings can, at any stage for A3 and A4 assume control of the ship.

Monitoring of the ship during operation for the first three degrees of automation – A0 to A2 – is the sole responsibility of humans, while for the last degree of automation – A4 – it is purely by the vessel's system. For degree A3, shared monitoring by the systems and humans is required.

Extremely interesting is the location of the human beings for performing this monitoring activity. It is quite clear that only in the first degree of Automation A0 are human beings required to be onboard the vessel. For the rest, monitoring can be done remotely from an RCC.

There is clearly a linear change of responsibilities for columns 1 to 6 between the vessel’s systems and humans as the levels of automation change from A0 to A4. Responsibilities by the vessel’s systems intensify as the degree of automation increases. However, column 7, suggests that the need for humans onboard the vessel vanishes abruptly from A2 onwards. Humans do not have to be onboard the ship, and this may adversely result in a much steeper decline in mariner employment.

Some of the questions that immediately arise are: just how likely is each of the automation degrees described above likely to take place, and how soon will that be? In other words, what is the state of the art in developing systems that will allow transitions between these degrees of automation currently?

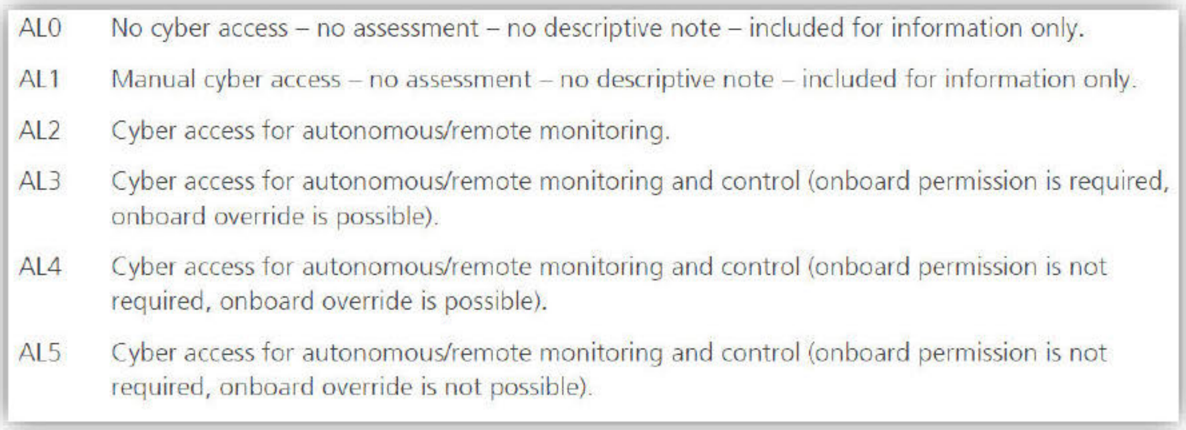
These questions become even more relevant if the other regulatory instruments also show similar trends like this one, and if there is generally some convergence in the regulatory framework. Next, the rest of the data collection instruments are explored before delving into further research on the questions that immediately arose above.

3.3.2 Instrument 2: Cyber-enabled ships: ShipRight procedure assignment for cyber descriptive notes for autonomous & remote access ships *(Lloyd's Register, 2017)*

Lloyd's Register (LR), instead of classifying the vessels themselves, classifies the ships' systems according to the level of cyber accessibility the systems have. At the lowest level, the ships' systems have no cyber accessibility, while at the highest level, the systems can be accessed fully via the internet. Of course, any ship may have a combination of these: systems with no remote accessibility and those with full remote accessibility via the internet for instance, which would make them hard to classify. To simplify the discussion below, an assumption will be made that a ship containing systems of a certain uniform cyber accessibility level, will be classified under the same access level.

Based on the various cyber access levels a mariner will have to a ship, Lloyd's report defines six access levels *AL0* to *AL5* shown in Table 4 below.

Table 4: Degrees of Access Levels for Cyber Ships – (Lloyd's Register, 2017, pp. 9-10)



AL0	No cyber access – no assessment – no descriptive note – included for information only.
AL1	Manual cyber access – no assessment – no descriptive note – included for information only.
AL2	Cyber access for autonomous/remote monitoring.
AL3	Cyber access for autonomous/remote monitoring and control (onboard permission is required, onboard override is possible).
AL4	Cyber access for autonomous/remote monitoring and control (onboard permission is not required, onboard override is possible).
AL5	Cyber access for autonomous/remote monitoring and control (onboard permission is not required, onboard override is not possible).

AL0 represents a vessel whose systems have no cyber accessibility. This type of ship is manned for every activity onboard and has full dependence on the crew for its safe operation. *AL1* ships have systems that can be manually connected to by the crew which also has to be physically located onboard the concerned vessel. No cyber accessibility to any system exists for the crew and there is no possibility for remote monitoring or control. Some physical connection to any system desired to be interacted with is a necessity.

Remote access becomes a possibility from *AL2*. At this level, the vessel's systems can now be accessed via cyber connection – whether it is the internet or radiofrequency (Lloyd's Register, 2017). The accessibility is limited to situation awareness only, which can be done from an RCC located either onboard the vessel or at a remote location. No remote control is possible.

With *AL3*, remote controlling becomes possible and enabled. This can be achieved by either an onboard crew or systems or by operators or systems located at an RCC away from the vessel.

However, the control needs authorization from onboard the vessel. Any command to the ship via remote control can be overridden by the crew onboard the vessel.

The main difference between *AL4* and *AL5* is that with the former, a possibility exists for control commands to be overridden by the crew onboard the vessel while with the latter, this is impossible. For both accessibility levels, all systems are cyber access enabled, and their monitoring and control can be done remotely by either systems or crew onboard the vessels, or operators or systems located in an RCC at a remote location.

Table 5 below shows the standardized format for Lloyd's Review's Access Levels. Column 1 clarifies how humans, with Lloyd's regulation, can be quickly replaced as far as information acquisition (situation awareness) is concerned. From as low accessibility as *AL1*, the vessel's systems start getting involved in information acquisition, taking over fully from *AL2*.

Table 5: Standardized Representation of Lloyd's Autonomy Degrees

0	1	2	3	4	5	6	7
Autonomy / Automation Degree	**Information Acquisition**	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
AL0	**H**	**H**	**H**	**H**	**H**	**H**	**H**
AL1	**S/H**	**H**	**H**	**H**	**H**	**H**	**H**
AL2	**S**	**S/H**	**H**	**H**	**H**	**H**	**H**
AL3	**S**	**S/H**	**S/H**	**S/H**	**S/H**	**S/H**	**H**
AL4	**S**	**S**	**S**	**S**	**S/H**	**S/H**	**S**
AL5	**S**	**S**	**S**	**S**	**S**	**S**	**S**

Information Analysis in column 1 seems to have a perfectly staggered transition across the *AL* levels: It is purely by humans for *AL0-AL1*, becomes a shared responsibility for *AL2-AL3*, and finally becomes the sole responsibility of the vessels' systems for *AL4-AL5*.

In columns 3-6, it is understood that the responsibilities of monitoring, making decisions, initiating action, and the control of the ship remain with humans up to *AL2*. Humans start relinquishing responsibility for task ownership by sharing them with the system at *AL3*. The system fully takes over the task of making decisions and initiating action in *AL4,* while it only assumes full responsibility for vessel monitoring and control in *AL5*. It is also understood that humans are required to be permanently onboard the ship up to *AL3,* while for *AL4* and *AL5*, they can be located at an RCC.

A similar trend in Lloyd’s Review as in Bureau Veritas regulations is observed here. In Lloyd’s Review, however, a tendency to hold on to activities for longer by humans is observed, suggesting a somewhat more conservative approach to technology adoption. The main questions that arose in the previous sub-section remain.

3.3.3 Instrument 3: Maritime Autonomous Ship Systems UK Industry Conduct Principles and Code of Practice *(Maritime UK, 2021)*

Realising the recent acceleration towards the development of MASS, Maritime UK saw it necessary to publish a guideline on MASS. This guideline is aimed at assisting various stakeholders in the MASS community including builders, owners, and operators of ships – MASS in particular – including ships under 24m in length (Maritime UK, 2021). In the guideline, some six levels of control for MASS are listed and are coded *Level of Control* (*LoC*) *0* to *5*. Table 6 below illustrates this depiction.

Worth noting from the guidelines is that within a given ship, various systems may have different *LoC* (Maritime UK, 2021, p. 21). This is similar to what was dealt with in the previous sub-section dealing with Lloyd's Review. A similar assumption as in that sub-section is therefore made here: that a vessel reaches the *LoC* when all its systems have a minimum of that *LoC*.

Table 6: MASS Levels of Control definitions (Maritime UK, 2021, p. 20)

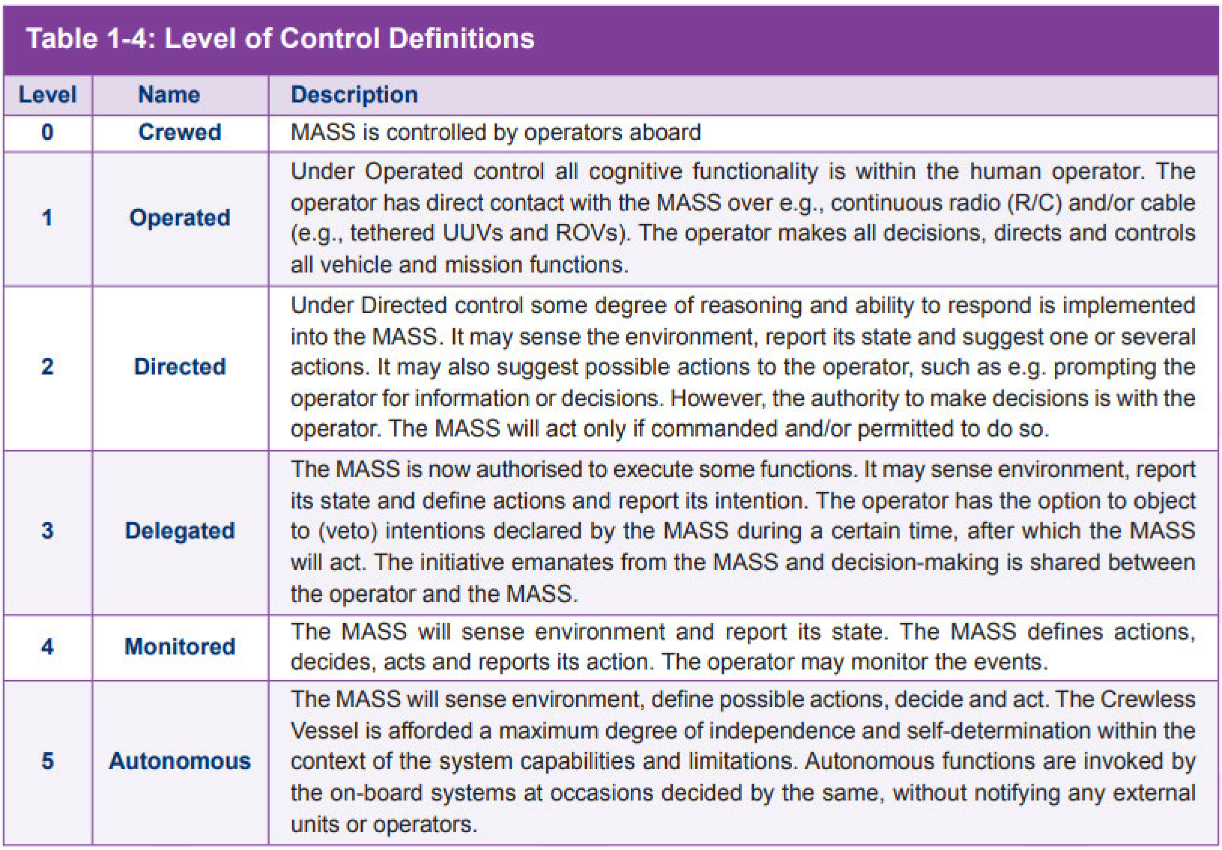


Table 1-4: Level of Control Definitions

Level	Name	Description
0	Crewed	MASS is controlled by operators aboard
1	Operated	Under Operated control all cognitive functionality is within the human operator. The operator has direct contact with the MASS over e.g., continuous radio (R/C) and/or cable (e.g., tethered UUVs and ROVs). The operator makes all decisions, directs and controls all vehicle and mission functions.
2	Directed	Under Directed control some degree of reasoning and ability to respond is implemented into the MASS. It may sense the environment, report its state and suggest one or several actions. It may also suggest possible actions to the operator, such as e.g. prompting the operator for information or decisions. However, the authority to make decisions is with the operator. The MASS will act only if commanded and/or permitted to do so.
3	Delegated	The MASS is now authorised to execute some functions. It may sense environment, report its state and define actions and report its intention. The operator has the option to object to (veto) intentions declared by the MASS during a certain time, after which the MASS will act. The initiative emanates from the MASS and decision-making is shared between the operator and the MASS.
4	Monitored	The MASS will sense environment and report its state. The MASS defines actions, decides, acts and reports its action. The operator may monitor the events.
5	Autonomous	The MASS will sense environment, define possible actions, decide and act. The Crewless Vessel is afforded a maximum degree of independence and self-determination within the context of the system capabilities and limitations. Autonomous functions are invoked by the on-board systems at occasions decided by the same, without notifying any external units or operators.

The detailed nature of Table 6 above makes it unnecessary to re-present its content. The focus will shift straight to putting together the standardized version in Table 7.

LoC0: Crewed represents a ship with no possibility of being remotely controlled. It is fully manually controlled by humans physically present onboard the vessel. This implies that all tasks in Table 7 for *LoC0* – Information acquisition, its analysis, the vessel's monitoring, making decisions, and its control – all lie with humans or mariners.

For *LoC1: Operated*, the cognitive aspect is done by the humans involved in the operation of the ship. This implies that humans analyze the information acquired, make decisions and initiate actions as listed in columns 2 to 4. The ship has systems that require a manual connection via some physical means such as cables. An operator monitors and controls the ship as depicted in Table 7's columns 5 and 6. Information acquisition is done by the systems on the ship, but with the operator physically in the vicinity of the vessel, information acquisition becomes a shared responsibility between humans and the ship's systems.

Compulsory on-board manning (Column 7 in Table 7) is not clear. This is because the guidelines include ships smaller than 21 meters which may be too small to have humans onboard. However, it is deducted that operators can connect to such small vessels via a physical means as a cable, while for a large enough vessel, a person should be onboard.

Table 7: Standardized Representation of the Maritime UK' LoC

0	1	2	3	4	5	6	7
Autonomy / Automation Degree	**Information Acquisition**	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
LoC0	**H**	**H**	**H**	**H**	**H**	**H**	**H**
LoC1	**S/H**	**H**	**H**	**H**	**H**	**H**	**-/H**
LoC2	**S**	**S/H**	**H**	**H**	**H**	**S/H**	**-/H**
LoC3	**S**	**S**	**S/H**	**S/H**	**S/H**	**S/H**	**S**
LoC4	**S**	**S**	**S**	**S**	**S**	**S/H**	**S**
LoC5	**S**	**S**	**S**	**S**	**S**	**S**	**S**

LoC2: Directed has some cognitive functioning built into the ship's systems. Through them, the ship may sense the environment, process, and report its state, as well as make suggestions for actions to be taken. It may not make a decision. At best, it only prompts the mariner for such and only responds to her commands. The control lies strictly with humans. It is not clear how connections or communications are made with the ship, but it is assumed that if the ship is large enough, then the operator must be onboard, otherwise, the connection is by cable to a nearby RCC. This

assumption is because the operator makes the final decision and not the systems with limited rights. So, in Table 7, information Acquisition is done by the system, while its analysis and monitoring may be done by both the system and the operator (human). Making decisions, initiating action and overall control of the vessel (columns 3-6 in Table 7) remain with the humans in its control.

Entry '-/H' is used in column 7 for *LoC1* and *LoC2*. This is because, for small enough vessels, mariners may not be accommodatable on board, but will still be somewhat physically connected to the ship, while for large enough vessels, mariners will be on board. For this thesis, wherever this entry '-/H' will be taken as 'H' because it deals with ships large enough to accommodate mariners onboard. The vessels it deals with are those of size 3000 Gross Tonns or more and equipped with propulsion power of 3000Kw or higher as discussed in sub-section 1.4.

A *LoC3: Delegated* ship is more authorized to perform certain functions. It collects information from the environment, processes and analyses the information collected, defines what should be done, and finally report its state and intention. The mariner has a limited period to react to the suggestions by the vessel, after which, if no reaction has been made, MASS then executes its intentions. There is some level of deciding authority given to MASS for this *LoC*.

At this level, the system has the capability and may perform responsibilities in columns 1-6 in Table 7. Although not specified outright in the guidelines, it is concluded that the mariner does not have to be onboard the vessel. This deduction is made from the fact that the system may decide on the human being's behalf. While the system becomes solely responsible for information acquisition and analysis of the condition of the ship and its environment, the responsibilities of taking decisions, initiating action, monitoring, and overall control can be assumed by the operator.

LoC4: Monitored allows the operator to only monitor the events as the system executes everything. All of the vessel systems are, for this level, enabled to act without authorization. It is not explicitly mentioned in the guideline, but it is believed that the monitoring happens so that the operator may intervene whenever needed. Therefore, all Table 7 entries for *LoC4* are assigned an "S" for System, except for monitoring, which is shared between the system and humans. Monitoring is therefore assigned "S/H". There is no need for a human being onboard the vessel and for this reason, column 7 is assigned an "S" as well.

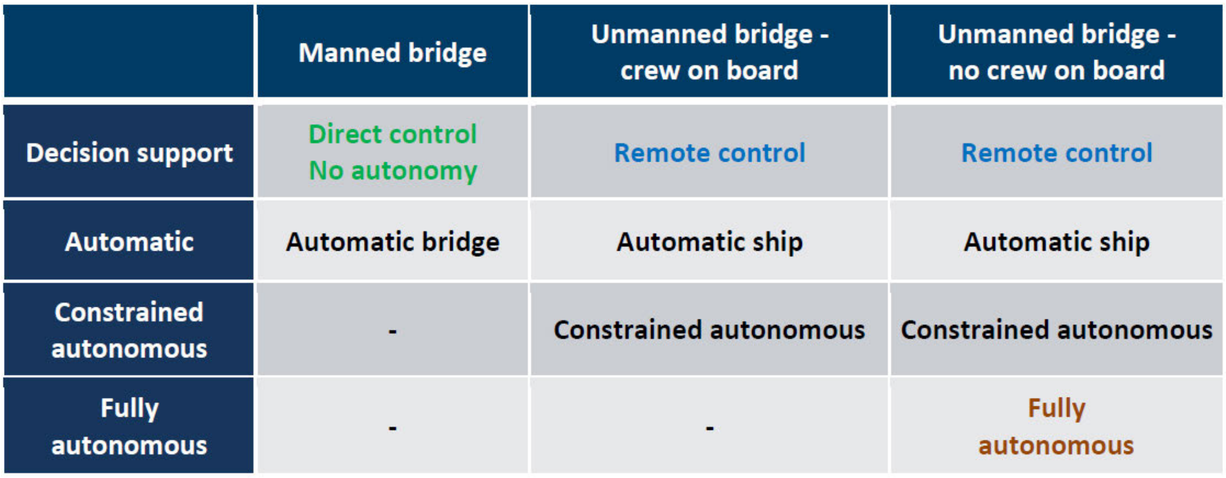
Finally, *LoC 5: Autonomous* implies full autonomy for the vessel. The ship is not manned at all and can perform all functions without being monitored or given permission by any human being. Various functions are invoked by onboard systems with no need at all for interacting with external parties. For this reason, all columns are assigned an "S" in Table 7.

In general, this sub-section leaves similar questions as in sub-sections 3.1 and 3.2, which are fully outlined in section 3.1 only. The next two sub-sections, dealing with two more data sources, are explored first before addressing these questions.

3.3.4 Instrument 4: Definitions for Autonomous Merchant Ships *(NFAS, 2017)*

The Norwegian Forum for Autonomous Ships (NFAS) defines six autonomy degrees, which can be found in Table 8 below. Presented in a slightly different way than seen thus far, the six types are a result of two variables: Operational autonomy level and Bridge manning level. The former can be seen along the rows of Table 8, while the latter can be seen along the columns. The six autonomy degrees are, therefore 'Direct control, no autonomy' (*DC*), 'Remote control' (*RC*), 'Automatic Bridge' (*AB*), 'Automatic Ship' (*AS*), 'Constrained Autonomous' (*CA*), and 'Fully Autonomous' (*FA*).

Table 8: Six Ship Autonomy Types by NFAS (NFAS, 2017, p. 12)



	Manned bridge	Unmanned bridge - crew on board	Unmanned bridge - no crew on board
Decision support	Direct control No autonomy	Remote control	Remote control
Automatic	Automatic bridge	Automatic ship	Automatic ship
Constrained autonomous	-	Constrained autonomous	Constrained autonomous
Fully autonomous	-	-	Fully autonomous

At the lowest level in terms of autonomy is *DC*. This ship is the type that is continuously manned on the bridge onboard the vessel and has some extremely basic automated systems. NFAS argues that this is, strictly speaking, not autonomous, but is necessary to include in the list for completeness of the taxonomy (NFAS, 2017). The crew, located onboard and continuously on the bridge, monitors, and controls the ship.

For an *RC* ship type, the level of automation is more advanced to allow for periodically unmanned operation at the bridge. The bridge does not have to be located onboard the vessel; it may be located at an RCC away from the ship itself. Cases, where the bridge is unmanned, may include, for example, the mustering period for the crew located onboard the vessel according to NFAS (2017).

The *AB* type of ship remains continuously manned on the bridge, but with a bridge that may have some advanced-enough automation that it controls the vessel. The crew merely monitors the bridge and can override some of the decisions at any point and take control of the ship. For an *AS* ship, the bridge automation becomes advanced to an extent that continuous manning on it becomes unnecessary. This periodically unmanned bridge may be onboard the vessel or at an RCC.

Both the *AB* and *AS* types are automatic, implying that they can perform relatively complex operations without humans. These operations will typically be sequentially pre-programmed, and only in two cases will the system call or notify a crew member or an operator for intervention: if the pre-programmed sequence is interrupted, or if the pre-programmed sequence has reached the final step.

For the ship type definitions covered thus far, there is limited clarity on the technological differences that require a bridge to be continuously manned (*DC* and *AB*) and periodically unmanned (*RC* and *AS*). The presentation of the text and Table 8 suggests that the levels of automation remain the same (*DC* to *RC*, and *AB* to *AC*), and only the manning requirements change. Could the difference lie in the communication capabilities of the ship between the crew or operators and the bridge? In other words, is a periodically unmanned ship equipped with communication capabilities that allow humans to remotely monitor that bridge, and only return if intervention is needed? If so, then why is this not clearly defined in the text itself?

The fifth autonomous ship type is the *CA*. This type is never continuously manned on the bridge. It is only periodically unmanned with the crew either onboard the vessel or located at an RCC away from the ship. The autonomy levels are quite high. The ship has a much wider scope of autonomous operation. It can handle problems commonly encountered during operation. It is equipped with various options of problem-solving capabilities, which it performs, however, within strict limits. If the limits are exceeded, it notifies humans for intervention. The humans are there merely as supervisors, only intervening once requested by the system.

Finally, type *FA* requires no human beings at all. Personnel is required neither onboard the vessel nor at an RCC. This is the most advanced and complex of the autonomous ship types; a fully autonomous one. It is understood that only in extreme failure situations and emergencies such as fire will it require to be boarded by humans. It has multiple built-in redundant systems that allow it to make it back to shore for attention in cases of minor failures.

Table 9 below shows the standardized version of this classification by NFAS. A *DC* ship requires the crew to assume responsibilities listed in columns 1 to 6. The reason for this is that the autonomy is so low that humans cannot be away from the bridge. Humans, therefore, need to be onboard.

For an *RC* ship, however, since humans do not have to be at the bridge all the time whether located onboard the ship or at an RCC away from the vessel, responsibilities such as information acquisition and information analysis in columns 1 and 2 respectively can be by either party: the systems or the humans. Monitoring and control, as well as decision making, and action initiation remain strictly responsibilities of the crew or operators of the vessel.

With an *AB* ship, however, the system can perform some responsibilities in the ship. For other responsibilities, it needs help from the crew. The crew was described earlier as being continuously on the bridge, monitoring and ready to intervene. At first glance, only the crew may do the monitoring of the ship, but strictly speaking, if an *AB* ship can perform some functions without human beings, then it is reasonable to expect it to monitor them as well. This is not explicitly declared in the text, however.

Table 9: Standardized representation of the NFAS Six Autonomous Ship Types

0	1	2	3	4	5	6	7
Autonomy / Automation Degree	**Information Acquisition**	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
DC	**H**	**H**	**H**	**H**	**H**	**H**	**H**
RC	**S/H**	**S/H**	**H**	**H**	**H**	**H**	**S**
AB	**S**	**S**	**S/H**	**S/H**	**S/H**	**S/H**	**H**
AS	**S**	**S**	**S/H**	**S/H**	**S/H**	**S/H**	**S**
CA	**S**	**S**	**S**	**S**	**S**	**S**	**S**
FA	**S**	**S**	**S**	**S**	**S**	**S**	**S**

It is also not clear which responsibilities would be left to the humans and which to the system. To fully fill Table 9 in, some assumptions are required. Based on the previous autonomy ship degree – *RC* – it can therefore be assumed that:

- what the system was able to do in an *RC,* it can certainly do in an AB;
- what the system shared with humans in an *RC*, it can now do without help from humans; and
- what the system could not do in an *RC*, it can now share with humans.

These assumptions enable us to fill in columns 1 and 2 with an "S" (which were "S/H" for *RC*); and columns 3 to 7 with an "S/H" (which were "H" for an *RC*). The first assumption does not have to be applied for column 7, however, because the text states that an *AB* must be strictly manned onboard the vessel. Column 7 is therefore filled with an H.

An *AS* ship was earlier described as being the same as an *AB* ship but with the possibility for the crew to be periodically away from the bridge. Columns 1 to 6 are therefore the same for *AB* and *AS* ships, with only columns 7 being different. Column 7 shows how an *AS* ship can be without a crew onboard.

A Constrained autonomous (*CA*) ship, on the other hand, exhibits significant independence from the human operator. It strictly requires no continuous manning on the bridge and performs all functions without assistance – provided they are within defined limits. With no strict requirement for the crew to be located onboard the vessel, all columns in Table 9 for a *CA* get allocated an “S”. This should be strange, knowing that there is one more autonomous ship type above this one – the *FA*.

The *FA* is a fully autonomous ship; one which is completely unmanned, neither onboard the vessel, nor at an RCC. It performs all functions without assistance from humans. All columns in Table 9, therefore, get assigned an “S” for an *FA* as well. It should be noted that according to the definition of this ship, no RCC is required. Therefore, what distinguishes an FA from the CA ultimately, would be the requirement for an RCC, and the manning thereof, for the latter.

3.3.5 Instrument 5: Maritime Safety Committee (MSC) 100th session *(IMO, 2018b)*

The International Maritime Organization (IMO) also contributed to the definition of the degree or levels of autonomy for MASS. These autonomy degrees were identified and defined to assess IMO regulatory instruments on how they may, or may not, apply to MASS. As an international body – and one which arguably many countries may look up to, to keep up with progress on MASS development – it was deemed necessary to add its degree of autonomy categorization data in this research work.

Some four degrees of autonomy are defined by the IMO's MSC and can be seen in Table 10 below.

Table 10: IMO Degrees of Autonomy (Maritime UK, 2021, p. 19)

1	**Ship with automated processes and decision support.** Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
2	**Remotely controlled ship with seafarers on board.** The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
3	**Remotely controlled ship without seafarers on board.** The ship is controlled and operated from another location. There are no seafarers on board.
4	**Fully autonomous ship.** The operating system of the ship is able to make decisions and determine actions by itself.

A *degree 1* ship is automated but requires decision support. Not all the systems and operations should be automated because the ship is manned with a crew that can take control as and when needed. No RCC control is needed.

A *degree 2* ship on the other hand, while manned with a crew onboard, is controlled from an RCC by an operator. The mariners onboard the vessel are available to take over the controls as and when required. Both RCC and on-board control of the vessel are possible with this level of autonomy.

With no seafarers onboard the vessel, a *degree 3* ship is controlled from an RCC by an operator. A *degree 4* is one controlled by an operating system capable of making decisions and performing various functions with no intervention from humans.

The IMO evidently takes a very simplified and simplistic view of the degrees of MASS compared to those already looked at in the preceding sub-sections. This may pose a challenge in interpreting them for the purpose of filling in the standardized representation of their degrees of autonomy, but it is necessary to do so to compare these degrees to those prescribed in the other instruments. After all, the IMO may have taken this simplistic approach to allow further innovation for this novel technology in the industry. Table 11 below shows the standardized version of the IMO classes.

Table 11: Standardized version of the IMO MSC Degrees of Autonomy for MASS

0	1	2	3	4	5	6	7
Autonomy / Automation Degree	**Information Acquisition**	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
1	**H**	**H**	**H**	**H**	**H**	**H**	**H**
2	**S/H**	**H**	**H**	**H**	**H**	**H**	**H**
3	**S**	**S/H**	**S/H**	**S/H**	**S/H**	**S/H**	**S**
4	**S**	**S**	**S**	**S**	**S**	**S**	**S**

From the explanation of *degree 1* earlier, it is understood that the system is only partially automated, but lacks the cognitive capability to perform any of the responsibilities in columns 1 to 6 in Table 11. A crew onboard the vessel is needed to assume all the tasks to monitor and control the vessel. The crew acquires information, analyses it, makes decisions, and initiates appropriate action.

With the control of the vessel done remotely from an RCC for a *degree 2* vessel, its systems must at the very least be able to acquire information. Further, it is assumed that since the crew onboard may take over controls at some point, it most likely does some information acquisition as well.

It is not clear if the vessel can perform any analysis of the information it acquires, but an assumption is made that with a manned RCC, and some crew onboard, it is more likely that the system is either not capable, or required to, or allowed to do so. The RCC operators or the crew onboard the vessels more likely performs information analysis when they take over controls. It is reasonable, therefore, to conclude that for a *degree 2* vessel, monitoring and control, decision making, and initiating action are all left to humans – whether located onboard the vessel or away from it at an RCC.

With *degree 3*, even more, ambiguity exists, except for two facts: Information acquisition is done by the ship's systems and the vessel is not manned onboard during normal operation. These facts make possible the filling of entries for columns 1 and 7: an "S" for both. It is not clear, however, who controls the vessel from the RCC: Is it a human operator, an RCC system, or both? Similar to a case analysed in the previous sub-section, some assumptions will have to be made, at least based on the previous level of autonomy. It is therefore assumed that:

- what the system was able to do in *degree 2*, it can certainly do in *degree 3*;
- what it shared with humans in *degree 2*, it can now do without help from humans; and
- what the system could not do in *degree 2*, it can now share with humans.

Columns 2 to 6 in Table 11 for *degree 3* are therefore labeled as shared tasks between humans and systems, all located remotely at an RCC.

Degree 4 possibly presents one of the cases with the least ambiguity. Completely unmanned onboard and controlled by ship-board systems only, this ship is evidently capable of collecting its information, analyzing it, making decisions, and acting upon them. The ship’s systems monitor and control it. All columns for a *degree 4* ship in Table 11, therefore, get assigned an “S”.

3.4 Collected data on mariner occupations

Maritime occupations are regulated. Entering its labour pool generally comes with minimum entry requirements. In South Africa, for example, a minimum of 2 semesters at an institution of higher education is required before one can join a shipping company as a cadet. Career advancement within the industry is both structured and regulated (SAMSA, n.d.). There is, however, no shortage of information on these occupations. Good coverage of what the jobs typically entail, what the minimum entry requirements are, as well as what experience and further certifications are required to advance to higher levels exists. MASS is primarily targeted at replacing all these occupations. However, to assess its success prospects in this regard, and the rate at which that objective is likely to be realised – if at all – requires thorough exploration of these occupations.

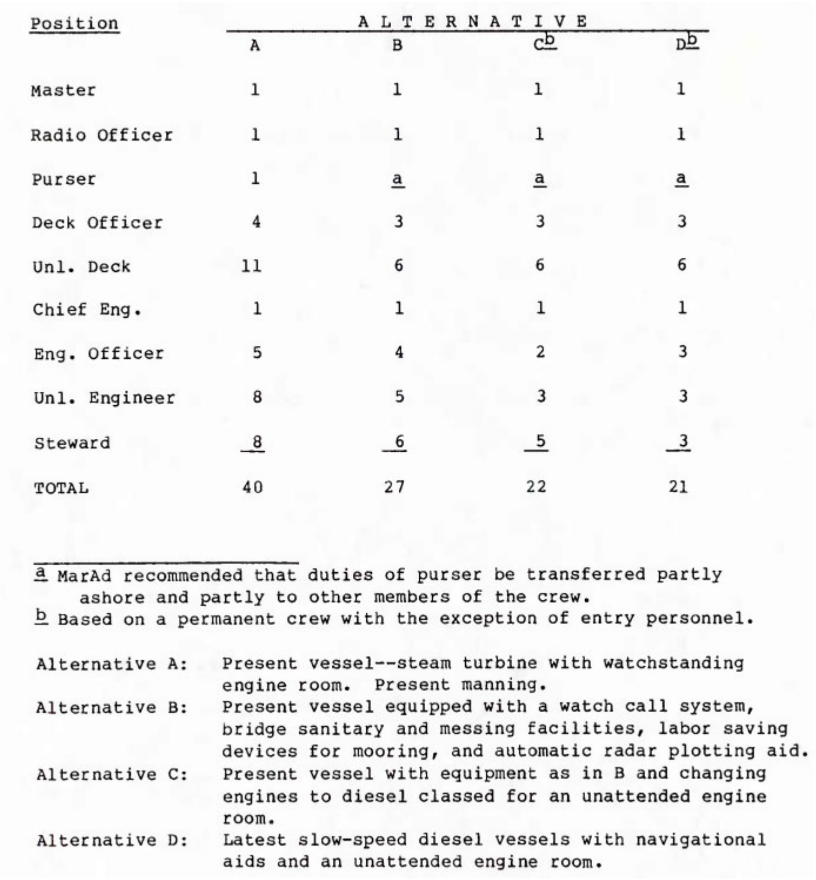
This subsection of the chapter, therefore, presents collected mariner occupation data in a structured manner: a ship's organization covering all occupational levels and the types of activities covered by each occupation. This is done in preparation for an in-depth analysis in the next chapter – Chapter 4.

Some of the occupations filled by mariners on merchant ships have evolved while others have become extinct. Cattlemen and Donkeymen are amongst occupations never heard of anymore, while those like Trimmers and Marconi operators may have either evolved or become integrated into newer occupations owing to, amongst others, improvements in technology and regulations (MHA, 2011). Table 12 below, for example, shows what the Committee of Effective Manning (1984) reported as the findings of a study by the MARAD on improvements in manning owing to technological and organizational changes on container ships. Grabowski and Hendrick (1993) confirmed similar reasons for the improvement in crewing up a ship. Mäenpää (2000) also adds to the argument about technological advances in the shipping industry having caused a major shift in vessel crew sizes and industrial relations in the marine sector at the turn of the 19th century.

This chapter explores the existing occupations onboard a merchant vessel to later establish which of them will experience any of the following changes due to increased autonomy for vessels:

i. Remain the same
ii. Become redundant
iii. Expand
iv. Shrink

Table 12: Alternative Manning of Container Ships



Position	ALTERNATIVE			
	A	B	C[b]	D[b]
Master	1	1	1	1
Radio Officer	1	1	1	1
Purser	1	a	a	a
Deck Officer	4	3	3	3
Unl. Deck	11	6	6	6
Chief Eng.	1	1	1	1
Eng. Officer	5	4	2	3
Unl. Engineer	8	5	3	3
Steward	8	6	5	3
TOTAL	40	27	22	21

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[a] MarAd recommended that duties of purser be transferred partly ashore and partly to other members of the crew.

[b] Based on a permanent crew with the exception of entry personnel.

Alternative A:	Present vessel--steam turbine with watchstanding engine room. Present manning.
Alternative B:	Present vessel equipped with a watch call system, bridge sanitary and messing facilities, labor saving devices for mooring, and automatic radar plotting aid.
Alternative C:	Present vessel with equipment as in B and changing engines to diesel classed for an unattended engine room.
Alternative D:	Latest slow-speed diesel vessels with navigational aids and an unattended engine room.

3.4.1 The Ship's Organizations

3.4.1.1 The Ship Master

At the helm of a vessel's oversight is the shipmaster. Also referred to as the captain, the master is responsible for the management of the vessel. Everyone onboard the vessel either directly or indirectly reports to him. All activities are coordinated to achieve his command. Vojković and Milenković (2020) list three divisions of the authority of the captain, as being the safety of the ship, public authorization, and representation of the shipowners. The master is therefore understood to be responsible for the vessel, everything, and everyone in or on it. He is also responsible for the environment around the ship. To achieve these, the master ensures compliance with all regulations around the operation of the vessel following those of the flag the vessel flies, as well as those governing the waters within which the vessel sails (CSL, 2021).

Directly reporting to the master are 3 officers from 3 departments in the ship, namely: Deck department, Engine room department, and Stewads' department. Next, we look at the various occupations within each of these departments, and the typical responsibilities of each.

3.4.2 The Deck Department

3.4.2.1 The Chief Officer

This is one of the three officers of the watch. The chief officer, also known as the chief or first mate, is the person responsible for all operations in the deck department and is second in charge after the master. He is responsible for the crew and the safety of the master. He is responsible for implementing company rules, and policies by the company – ensuring adherence to all regulations, processes, and procedures by the crew and onboard equipment (CSL, 2021; MHA, 2011 & Kitchen, 1980).

Kantharia (2021) and Irish Maritime Development Office (2021) list duties of the chief officer as including:

- Vessel navigation, and is accountable for vessel stability
- Scheduling and distribution of work to crew
- Training of crew and ensuring adherence of the same to various regulations such as MARPOL, SOLAS, and STCW
- Cargo operations – including planning, loading, and unloading of cargo, the cargo handling equipment, and the safety of cargo onboard the ship
- Ballast and de-ballast operations performed from onboard the vessel
- The maintenance of the ship's hull and accommodation, lifesaving, and fire-fighting equipment, and ultimately the safety of everyone onboard
- The maintenance of the various parts of the ship is not within the scope of the engine room – including ensuring maintenance stock is always purchased and available onboard.

While on duty, this officer stands watch on the vessel. The duties of this officer are more managerial and supervisory.

3.4.2.2 The Second Officer

Also one of the three officers on the watch, the second officer is responsible for the navigation of the vessel. This officer, who is also known as the second mate, is third in charge and assumes duties including the following tasks:

- Navigation tasks
- Medical administration tasks
- Communication tasks

As a navigation officer – the primary role of this occupation – the officer plans the voyage, updates, and broadcasts the charts as the vessel makes its way from the port of origin to its destination. The plans include berthing and unberthing, as well as the vessel's detailed voyage passage (CLS, 2021; MHA, 2011).

MaritimeCareers (2007) adds medical administrative tasks to this role, as well as communication tasks. For the former, this officer medicates seafarers onboard for minor sicknesses, but communicates and gets guidance from the shore on more serious sicknesses. For the latter, the officer ensures the proper functioning of communicating equipment. For this, maintenance and repair activities are coordinated by this officer to be either onboard or onshore. This officer communicates with the shore and stands watch during cargo working when docked at a port.

This officer certainly performs more manual work than the two discussed prior. Can the manual and administrative work be replicated by the ship's systems?

3.4.2.3 Third Officer

Being the most junior officer on the deck, this officer takes instructions from both the master and the chief officer. The duties of this officer include, but are not limited to:

- Weather / Meteorological tasks
- Life-saving equipment upkeep
- Watchkeeping during some shifts

This position is entry-level to officers on the deck as an officer of the watch. It typically is next after boatswain (see sub-section 3.4.2.4 below) in the deck department hierarchy. Weather details are collected and communicated to Meteorological organizations onshore through this occupation. All instruments enabling these tasks are for maintenance by this very officer (CSL, 2021; MHA, 2011 & MaritimeCareers, 2007).

Life-saving equipment includes free-fall lifeboats, Davit launched lifeboats, Life rafts, Man Overboard Boats (MOB), and rescue boats. There are also worn life-saving equipment such as life jackets, survival suits, Ring-life buoys, and self-contained breathing apparatus (Wolf & Vredeveldt, 2004) and (Singh, 2021). These powered and non-powered, inflatable and non-inflatable, as well as worn appliances and equipment, are all inspected, maintained, and kept up by this officer – the third mate – following the SOLAS regulations.

This role certainly comprises activities of supervision but also manual administrative work. Can the manual and administrative work be replicated by the ship's systems? At what degree of autonomy for MASS would supervision by the Bosun no longer be required?

3.4.2.4 Boatswain

Bhattacharjee (2019) classifies the duties of the Boatswain, who is also known as the Bosun into three main categories, namely:

- Supervision of the deck ratings
- Maintenance of the deck
- Mooring and Anchoring of the ship

As a supervisor, the Bosun plans, schedules, and assigns work activities to the deck ratings based on, amongst others, skill levels. The assigned work is typically passed down from the officers of the watch. The maintenance of the deck, its stores, and supplies are partly overseen by the Bosun, as well as efficient mooring and anchoring of the ship (MaritimeCareers, 2007; Bhattacharjee, 2019).

Although skilled and able to perform these tasks, the Bosun's role on the deck is understood as being more supervisory, and more hands-on only with the intention of either skills transfer or training. The question therefore is: would this role still be needed with a ship whose maintenance is performed in the ports, and one that is smart enough to safely berth with no human onboard?

3.4.2.5 Ratings: Able-Bodied and Ordinary Seamen

These crew members perform tasks assigned by the superiors on the ship and happen typically under the supervision of the Bosun or the officer of the watch. Able-bodied seamen are certificated while Ordinary seamen are not. The latter are typically the lowest level in a vessel's hierarchy and learn tasks such as cleaning, painting, knot-making, etc. The Able-Bodied seamen, on the other hand, have gone past the learning stage and are certificated. They assume roles such as the lookout, standing bridge watch as well as perform tasks such as steering the ship as Helmsman (CSL, 2021; MHA, 2011; MaritimeCareers, 2007).

3.4.3 The Engine Department

3.4.3.1 Chief Engineer

A manager and the most senior person in the engine department, the chief engineer is responsible for all machinery onboard the vessel: their proper functioning and maintenance. He oversees a team of officers and ratings in the engine room. The chief engineer and his department are guided by industry regulations and manufacturer's equipment manuals to achieve their goals (CSL, 2021; MHA, 2011; MaritimeCareers, 2007; EduMaritime, 2019).

While the engineer has a team reporting to him and taking turns for the watch of the engine room, he should always be on call. The functions of a chief engineer are all at a managerial level and are listed as follows in the STCW Table A-III/2 (EduMaritime, 2019b)

- Marine engineering at the management level
- Electrical, electronic, and control engineering at the management level
- Maintenance and repair at the management level
- Controlling the operation of the ship and caring for persons onboard at the management level

The functions above suggest that since the ship remains a vessel with complex engineering systems, there will surely always be room for a chief engineer. Some of the questions that arise are: To what extent will his involvement be required? Will it be dedicated to a single ship at a time or will he be able to split his time amongst various ships? Will he have to be on board the vessels to perform his roles or can they be done from an RCC?

3.4.3.2 Second Engineer

The second engineer, also known as the first assistant engineer, is the second in charge of the engine room. The STCW also calls for the same competence as the chief engineer, but this engineer is responsible for the day-to-day operation of the vessel. This engineer can stand stead of the chief engineer in his absence or incapacity to assume his duties (EduMaritime, 2019c).

This engineer's role is therefore also of a managerial nature, although MaritimeCareers (2007) states that this engineer performs repairs and maintenance in the propulsion plant. The same questions as that of the chief engineer hold concerning the impact of the introduction and roll-out of the various MASS degrees of autonomy.

If the two officers above are at a management level, then the question is who do they manage or supervise? Next, the occupations under their supervision, or more importantly, what they entail, are discussed.

3.4.3.3 Third and Fourth Engineers

The third and fourth engineers are engineers of the watch in the engine room (CLS, 2021). The STCW however, identifies the OICEW and DDE – the Officer in Charge of the Engineering Watch and Designated Duty Engineers respectively – as engineers of the watch. The OICEW is physically present in the engine room for a manned vessel, while the DDE is a designation for an officer responsible for a periodically unmanned Engine room (EduMaritime, 2019d). The STCW code Table III/1 states that these engineers should be competent at an operational level – suggesting a somewhat hands-on approach. It, therefore, lists the following, as some of the competencies expected of these engineers:

- Maintaining a safe watch (engine room watch that is)
- Operating main and auxiliary machinery and associated controls
- Operating fuel, lubrication, ballast, and other pumping systems and associated control systems
- Operating electrical, electronic, and control systems,
- Maintenance and repair of electrical and electronic equipment
- Appropriate use of hand and machine tools, and measuring devices
- Maintenance and repair of shipboard machinery and equipment
- Ensuring compliance with pollution prevention requirements
- Keeping the ship seaworthy
- Ensure safety (Fires, Medical, Life-Saving equipment)

These roles are evidently more hands-on than those by the officers they report to. Would MASS be able to survive without them onboard at all? It is understood that the DDE currently exists for periodically unmanned vessels, but could a vessel survive long-distance journeys without man onboard?

3.4.3.4 The Electro-Technical Officers (ETO) and Electro-Technical Ratings (ETR)

The ETO works closely with both the deck officers as well as the engine room officers. It is recorded that this mariner does not stand watch but works during the day. The activities covered by this occupation include ensuring the proper functioning of all things electrical and electronic onboard a vessel. With the high frequency of technological improvements, and vessels becoming more automated and intelligent through increased use of electronic and electromechanical systems, it is no surprise that this is considered one of the most important occupations onboard a vessel (EduMaritime, 2019e; CSL, 2021).

The importance of the role played by ETO has been under discussion for quite some time. As early as 1938, the committee on merchant marine and fisheries deliberated on the need for these technicians to be made licensed officers – to be afforded an opportunity to have equal authority with chief engineers onboard a vessel (Committee on Merchant Marine and Fisheries, 1938). Some years later, Hallstead, Richardson, & Friauf (1958) published some works looking at fatal accidents as a result of electrical shock onboard US Navy ships. An important issue highlighted was that the correct procedures by the electrical responsible persons on board the vessels were not diligent, resulting in the deaths of fellow mariners.

The ETO is responsible for maintaining and repairing all electrical equipment onboard – both in the engine room and on the deck. The ETO reports to the chief engineer. The ETR assumes a support role to the ETO and reports to it as well.

3.4.3.5 Engine Room Rating

The engine room ratings perform various semi-skilled and unskilled labour ranging from monitoring single equipment to repair work as mechanics by junior seamen and senior adult seamen respectively. Engine room storekeeping is typically also performed by an engine room rating. The count of persons and responsibilities are different depending on ship size. Larger ships may require more persons, while smaller ones typically employ less. In the latter case, more tasks may be assigned to a person than in the former case. Occupations typically assigned to ratings are Mechanic, Electrician, Greaser, Cleaner, Wiper, etc (Kitchen, 2017).

3.4.4 The Stewads' Department

This department is responsible for the galley and housekeeping onboard a vessel. On its reporting hierarchy are the Chief Cook / Steward, the Second Cook, and various ratings.

According to Mäenpää (2000), demand for catering on ships was improved by a transition from Sailships to Steamships, which made sea travel ever more comfortable, safer and increased its popularity. This author further attributes this rapid growth, to the development of the third group of sea workforces: The engineers' department.

One can clearly conclude from the above that the presence of the Stewards' department on a vessel is due to the presence of humans. The responsibilities of these Stewards' department occupations are discussed in the next few sub-sections.

3.4.4.1 The Chief Steward

The chief steward reports directly to the master of the vessel and is at the helm of the stewards' department. The responsibilities of this occupation include taking care of catering activities and general housekeeping onboard a vessel. The responsibilities may merely cover only the supervisory and leadership aspects or could include hands-on involvement in the performance of the activities of the department; planning, preparation, and serving of meals depending on the size of the ship and number of crew members. This role may also be responsible for the timing of meal servings. The cleaning and general up-keep of the officers' quarters and stewards' department may also be under this occupation's care or responsibility (DOL, 2005).

3.4.4.2 The Chief Cook and the Second Cook

This Chief Cook occupation oversees the preparation and ensuring the good quality of meals onboard a ship under the supervision of the Chief Steward. This role may be assisted by the Second Cook if present on the vessel. The Chief and Second cook roles are filled by personnel with five or three years prior experience respectively, in either a hotel or ship culinary, along with some culinary qualification (MaritimeInsight, 2019).

3.4.4.3 Ratings in the Stewards Department

Various other occupations belonging to the Stewards department are the Baker or Pastry man, the Galley utility man, and the cleaner. Baking, washing cooking utensils, and cleaning the galley respectively.

Chapter 4: Analysis

4.1 Introduction and Definition of Convergence and Divergence

This chapter is made of two sections. The first deals with checking whether the five classification instruments presented in subsection 3.3 exhibit convergent or divergent approaches toward MASS introduction.

Convergence for this study means alignment or agreeability among the instruments, to a notable degree, on the delegation of shipboard functions to humans (seafarers or mariners), ship's systems, or a combination of the two. Divergence means the opposite of the above, and that is a lack of alignment or agreeability, to a notable degree, on the delegation of shipboard functions to humans (seafarers or mariners), ship's systems, or a combination of the two.

Convergence will infer higher prospects of success in delegating those functions as intended, and therefore ultimately, higher prospects of success in MASS introduction. The impact on mariner employment onboard a vessel will be immediately expressed where convergence is evident. If divergence is evident, then an attempt to identify the most likely approach to be adopted will be made before an inference of the potential impact on mariner employment is attempted.

The second part of the chapter will then graphically express and explain the inter-connectedness of three things: The introduction and wide adoption of MASS; The resulting decline of the conventional ship as it is known today; and how seafarer employment on each the respective vessel group – i.e. MASS or conventional ship – could be affected. This second part will then conclude by expressing the overall inference on the impact of employment of mariners on merchant vessels globally.

4.2 Test for Convergence and Divergence towards MASS introduction and adoption

The standardized representations of the different levels of autonomy in tables 3, 5, 7, 9, and 11 express an intriguing story. Looked at broadly, the story depicted is that of convergence. There seems to be great agreeability in the approaches by the different regulatory bodies toward the classification of MASS. To unpack the story, two approaches will be used – the first being a layered, pictorial analysis, and the other a graphical visualization analysis – each aimed at giving the reader a different perspective but pointing to the same conclusion. The latter will be used to draw other inferences such as the systems that could possibly be converted and the order that will presumably be seen, as well as possible quantification of employment loss by mariners.

4.2.1 A Layered Pictorial Analysis Approach

Appendix B(i) presents tables 3, 5, 7, 9, and 11 in a coloured or layered representation. This is done by highlighting each cell with a distinct colour depending on the entry it has. For humans (H), grey is used; for ship's systems (S), blue is used; and for a combination of humans and ships' systems (S/H), orange is used. This is done to help highlight the resemblance if any.

What is immediately apparent to the eye is the consistency exhibited by the three distinct layers across all five instruments: there is clearly a top layer of grey for human-performed functions, a middle layer of orange for functions shared between humans and the vessel's systems, and a bottom layer of blue for vessel's systems-performed functions. This consistency holds for themes 1 to 6 which deal with shipboard functions on a vessel. One instrument shows a divided orange layer, suggesting divergence from the other instruments. The significance of this will be tested by exploring the most likely approach to be assumed. The last column, which deals with compulsory presence of humans on the vessel (theme 7), only shows two distinct colours: grey for compulsory presence of a mariner onboard and blue for lack of mandatory mariner presence on board the vessel. From a broad perspective, there is great consistency observed. The top part is predominantly grey, and the bottom is predominantly blue.

Delving deeper into detailed analysis, all five images are supported on a blue colour at the base from themes 1 to 7. This observation is of great significance because it certifies that the final goal is the same for all: A ship that has all onboard functions performed by its systems (themes 1 to 6), with no human onboard (theme 7). The alignment and agreement on this goal are remarkable. If this is the case, however, will mariners still be needed at all, or will any mariner job as it is known today have reached its end? If mariners will still be needed, then how many, and what will they be doing? To answer these questions, further insight is needed from the preceding levels of autonomy – the levels above the base.

Resetting back to the genesis of the MASS journey – that is, the upper-most rows of the 5 tables which represent the lowest levels of autonomy – only four-fifths (80%) of the tables are capped by a fully grey layer from theme 1 to theme 7. One-fifth (20%) starts with an orange colour. These observations suggest different perspectives of the ship as we know it today: 80% suggest that the level of autonomy is at its lowest and only humans perform all the functions listed without help from the vessel's systems, but the other 20% is more optimistic and suggests that today's ship has some notable level of autonomy for theme 1: information acquisition. However, this autonomy is low because it requires both humans and vessel's systems to work together (orange colour).

All tables agree that for this lowest autonomy vessel, humans must be onboard a vessel. From a manning perspective, therefore, there is absolute alignment.

Overall, therefore, there is great alignment and agreement on the perspective of today's vessel – from both autonomy (by a majority of 80%) and manning perspectives (100% agreement).

What these observations suggest therefore is that all crew members remain relevant and onboard a merchant vessel for its safe operation. With this level of autonomy, it is reasonable to expect no reduction in mariner employment.

Now, what has been gathered and proven thus far is massive convergence in both the early stages of MASS (today's ship) and the endpoint – the target, fully autonomous ship. However, how are the journeys between these two points mapped out by the various classification societies' tables? Are their approaches convergent? Can the world expect harmonious, collaborative, and well-aligned approaches by different regions of the world based on these available classifications instruments already available? Well, to figure this out, further exploration into the inner parts of the 5 tables is done next.

With the 5 instruments having total levels of autonomy ranging from 4 to 6, a level-by-level evaluation will not be possible further. Three steps will be taken to enable a continuation of the analysis for the inner parts of the table:

1. First, the tables are converted to pictures, and the row labels are replaced with an autonomy scale ranging from minimum at the top of the table to maximum at the bottom of the tables. This can be seen in Appendix B(ii).

   It is possible to do this only because it has already been established that the starting and the ending points of the ship-autonomy journey, or the top and bottom layers of the tables, have already been established to be the same across all classification tables under study.

2. Second, the pictures are adjusted vertically for them to be the same size or height. This can be achieved by either stretching the shorter ones to the height of the tallest (one with the most rows) or by compressing the taller ones to the smallest (least rowed) one's height.

   It is possible to do this only because (i) the tables have now been converted to pictures, (ii) their vertical scales (those showing autonomy levels) are now communized, and (iii) their lowest and highest autonomy levels have been proven the same.

3. Finally, each picture is divided into 5 sections labeled **L** for least autonomy, **LM** for low-to-medium autonomy, **M** for medium autonomy, **MH** for medium-to-high autonomy, and **H** for highest autonomy. This can be seen in Appendix B(ii)

To continue the evaluation of alignment or agreeability, the focus now moves to the **LM** layer. Quite notable is that for the first time, all 3 colours are represented in a single layer. Between themes 1 and 7, grey is the dominant colour, meaning that most societies still prefer the dominance of seafarer-performed functions.

Three-fifths (60%) of the instruments only convert a single function – information acquisition – to a shared task between seafarers and ship's systems, while one-fifth (20%) take a bolder step by converting information analysis as well to a shared task. The remaining one-fifth (20%) is again ahead of the rest by introducing a fully systems-controlled (blue) function at this autonomy level. The latter, the ahead-of-the-rest instrument, fully hands over the function of information acquisition to the vessel's systems while the information analysis becomes a shared task.

Overall, observed here are cautious moves towards autonomy being introduced by converting only a few tasks to shared mode, while the majority remain mariner performed. This is something observed in all instruments. This caution is further exhibited in the requirement for compulsory ship-based mariners. Three-fifths (60%) of the societies still require mariners onboards, while 40% generally accept non-ship-based mariners.

Overall, there is convergence to autonomy approaches to an acceptable extent; the common observation is that mariners are still required for this level of autonomy albeit some of them being located at an RCC.

With some tasks shared at this level, although cautiously so, it is reasonable to start expecting crew capacity freeing up, and consequently some employment reduction. Occupations that involve information acquisition and information analysis will therefore be the first to see a reduction in loading resulting in capacity-freeing.

In the deck department, the second and third officers, whose tasks include navigation and weather forecasting respectively, or each watchkeeping during their respective shifts, could be affected at this level. If enough of their capacity is freed, there could be a possibility to combine their roles into one. In the engine department as well, the third and fourth engineers could be the first to be affected at this level. Most of their tasks start with information acquisition and analysis before decisions are taken and actions are initiated. Keeping engine room watch involves reading and analyzing gauges and instrument data for example and no maintenance can be done prior to doing them. There is therefore a great potential for merging these positions with enough intelligence built into the vessel to automatically perform information acquisition and analysis.

Further, the possibility of RCC-based employment at this stage could result in further reduction in employment. It was established in chapter 3 that operators at an RCC may not be restricted to a single ship. When, at this level, an occupation is moved to being RCC-based and starts handling more than a single ship, a single equivalent job will be lost for every additional ship supported.

With all the reductions stated above, there may be a case for the stewards' department to reduce manning per vessel, especially in cases where RCC-based employment is adopted.

In the **M** region, about halfway to fully autonomous ships, the instruments generally exhibit a major shift towards shared tasks. The dominance of the orange colour (shared tasks) in this area, accompanied by the notable presence of the blue colour (ship systems' tasks), could well signify a turning point in mariner employment. In the previous region (**LM**), caution towards shifting tasks from humans to systems was generally observed. The turn of events in this **M** region would imply autonomy results having been achieved in the preceding, caution-filled **LM** region. That success could be the trigger point for a closer look at mariner occupations as their capacities continue being freed up through shared and fully systems-performed tasks. Notable in this region is how deciding authority (theme 4), initiation of action (theme 3), monitoring (theme 6), and control (theme 5) start transitioning from being reserved for mariners to being shared with the ship's systems. This is observed for four-fifths (80%) of the instruments, with the remaining one-fifth differing on deciding authority (theme 4) and ship monitoring (theme 6) function sharing. The remaining 20% of the instruments continue to be cautious by reserving these two functions purely for seafarers still.

A major shift to the relaxation of compulsory ship-based manning (theme 7) across the 5 classification instruments is also highlighted. In this region, there is less than 50% compulsory ship-based manning.

The observations above are not merely on some of the instruments, but on all. This is therefore yet another confirmation of convergence and alignment in the approach by the classification societies to full autonomy. The consequence that can be expected, therefore, is even further seafarer reduction.

For this **M** region, therefore, everything described for the **LM** region concerning mariner employment reduction is intensified. The major shift to shared tasks and the notable move to fully automating some tasks results in so much capacity freed that employment loss becomes certain and inevitable.

Consequential to the extent of fewer people on the ship, spaces typically allocated to accommodation facilities can be reasonably expected to reduce. These include cabins, gallies, food and waste storage facilities, recreational areas, etc. The saved spaces can then be re-assigned to cargo. Fewer people interacting with spaces and surfaces may result in less need for cleaning. For example, a deck could become fully enclosed and cargo-keeping. Also, machinery and equipment may suddenly require less maintenance as a result of less exposure to human interaction and mistakes. The need for deck and engine room ratings could reduce significantly. Consequently, the stewards' department crew size may reduce significantly.

As the overall responsible person for the ship, it is expected that while there are some mariners onboard, it may become difficult for the Master to be RCC-based. This will be the case despite decision making, action initiation, monitoring, and control of a ship gaining autonomy more rapidly. However, the same cannot be said for the second mate and the chief engineer. At this level of autonomy (the **M** level), the requirement for them to be ship-based could start reducing, and possibly fully diminish at the inception of the next autonomy level (**MH** level) if not slightly later.

Finally, between the **M** regions of the five instruments and their respective target fully autonomous ships' **H** regions, are the **MH** (Medium-to-High Autonomy) sections. Observed therein are a couple of points as outlined next. First is the full disappearance of fully man-performed functions because the grey colour disappears for themes 1 to 6. Second is a clear dominance of the blue colours representing some very apparent system-performed functions. Third, for three-fifths (60%) and four-fifths (80%) of the instruments respectively, the functions of ship control (theme 5) and of ship monitoring (theme 6) remain shared between seafarers and the ship's systems. Fourth and final, theme 7 reveals that no compulsory presence of mariners onboard a vessel exists any longer.

This stage – the **MH** stage – which comes after the dramatic seafarer-employment-reducing **M** stage is almost certain to contain the last crew members on a merchant vessel. Among these would most likely be the master, one or two supporting members – presumably an engine room employee such as a chief engineer, and a significantly shrunken stewards department.

At this stage, it can be reasonably expected that functions not yet fully handled by machines would mostly be shared between the very reduced ship-based crew members and RCC-based operators. What should be kept in mind is that the RCC-based operators could be operating several ships, which would result in significant employment loss in the industry.

A final observation of significance is that the ship monitoring function (theme 6) is one that seems will assume the slowest rate of full autonomy adoption. In the **MH** region, some 60% of the classification societies keep it as a fully shared task between seafarers and the ships' systems while

40% only fully hand it over to the ship's system very late in this autonomy level. This comes as no surprise at all, because listed as the primary role of the master in section 3.4.1 is overall vessel oversight which is understood as being the significant task of ship monitoring. This, just as discussed shortly beforehand, is the reason the Master is among – possibly even the last – to vacate the vessel in this journey to full autonomy.

At this point, finally, a view about the requirement of seafarers on board a vessel for the highest autonomy level **H** can be returned to and concluded – a question left unanswered from the third paragraph of this subsection (4.2.1).

As it seems, humans will be required. This will most likely be a team consisting of the Master and a deck department employee, as well as a chief engineer and an engine department employee. These four, however, will be RCC-based and be working with the ship-based systems to remotely operate the vessels. They will more likely collectively adopt the identity of operators, and no longer seafarers, as currently defined in some of the classification instruments.

The Stewards' department would cease to exist in its entirety, as would various ratings' jobs. Shore-based maintenance and repair companies would now become primary engineering service providers to ships, but would any of the persons employed therein need any STCW certification? This is not the case currently and would most likely not be in the future as these ship repair employees will remain very-likely shore-based. It is worth highlighting that there will be ship-based RCCs, which will very likely attract ship repair operators based on them. The belief, however, is that there will be fewer of the Ship-based RCCs due to the redundant systems that will be contained in MASS enabling them to continue operating during a failure, until return to shore for proper repair activities.

Now, from the current average ship-based crew of 21 to only four RCC-based operators in the future, there could be an average employment reduction rate of some 81% if these operators only worked on only single ship. This reduction would increase to about 90.5% if these four operators operated two ships simultaneously, 93.7% for three, and a massive 95.2% for four ships.

4.2.2 A Graphical Analysis Approach

In this subsection, a different approach to the analysis is adopted compared to the previous sub-section. Numbers are introduced and graphical representations of the tables are produced. This allows for three things: First, the ability to test if the same result is attained from a different analytical approach. Second, it is aimed at helping establish which systems are more likely to be automated first – that is, establish a rough roadmap from lowest-autonomy MASS development and introduction to fully autonomous MASS. This is only possible with assumption number 3 outlined in section 1.9. And last, this analysis approach will help establish the average approach to MASS introduction: a result of the mathematical combination of the 5 instruments presented. The standardized versions of the instruments – those are, tables 3, 5, 7, 9, and 11 – need to first undergo transformations to graphical representations. Below, a step-by-step explanation of how this is achieved in Table 5 is given. The rest of the tables are transformed similarly.

Focus here shifts from analysis along the rows to analysis along the columns and Figure 1 below should be used as a reference for the following step-by-step graphical transformation outline:

1. For each of the 7 themes in the standardized format in Figure 1(a), a count is done for entries “H”, “S/H”, and “S”.
2. A separate table is created for the results (see Figure 1(b)). On the top row, the results for “H” are entered, followed by the results of the count of “S/H” on the next row, and finally, the results for “S” on the bottom row.

   The arrangement of the rows here follows the general observation seen in sub-section 4.2.1 where grey or “H” occupied the top layer, blue or “S” occupied the bottom layer, and separating the two was the orange or “S/H” layer.
3. Each cell is then converted to a percentage, by dividing its value by the number of rows representing autonomy degrees for each instrument. This is done so that the instruments can be compared to each other. The entries in the cells of Figure 1(c), therefore, were obtained by dividing each corresponding cell value in Figure 1(b) by the number of rows in Figure 1(a) – the standardized format of table 5.
4. Finally, the percentage values are represented graphically in an area plot. This enhances the visualization of each value in its column. In this case, Figure 1(d) is the area plot of the percentage values in Figure 1(c).

Figure 1(d) is the resulting graphical visualization of table 5 (Figure 1(a)). Similarly, graphical visualizations for tables 3, 7, 9, and 11 are created and can be seen in Appendix D, but their area plots are collated in Appendix C for ease of cross-comparison.

Figure 1: Graphical visualization of Table 5

(a)

	1	2	3	4	5	6	7
Autonomy / Automation Degree	**Information Acquisition**	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
AL0	H	H	H	H	H	H	H
AL1	S/H	H	H	H	H	H	H
AL2	S	S/H	H	H	H	H	H
AL3	S	S/H	S/H	S/H	S/H	S/H	H
AL4	S	S	S	S	S/H	S/H	S
AL5	S	S	S	S	S	S	S

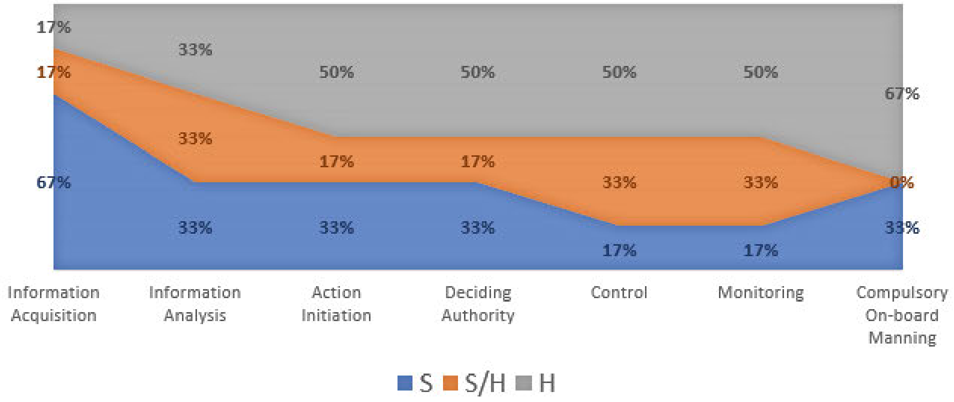
(b)

	1	2	3	4	5	6	7
	Information Acquisition	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
H	1	2	3	3	3	3	4
S/H	1	2	1	1	2	2	0
S	4	2	2	2	1	1	2

(c)

	1	2	3	4	5	6	7
	Information Acquisition	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
H	17%	33%	50%	50%	50%	50%	67%
S/H	17%	33%	17%	17%	33%	33%	0%
S	67%	33%	33%	33%	17%	17%	33%

(d)



Overall, the story painted by the graphical area plots in Appendix C for all instruments is of great agreeability. Overall, the top grey "H" layer, representing mariners, widens from left to right (theme 1 to theme 7), while the bottom blue "S" layer representing ships' systems narrows from left to right. Separating the two layers is an orange "S/H" field: a shared-task domain between mariners and vessels' systems. This field, which separates the exclusively mariner-performed task domain and the exclusively systems-performed task domain, starts higher up the left edge and slants downwards toward the right-hand edge for all the area plots. Clearly depicted here is great agreeability and convergence, overall, of the conversion of functions from being human-driven to being shared and finally, systems-driven.

Per function or task or column or theme, is there agreeability or convergence in the transition from being human-driven to ultimately being systems-driven?

Well, the first function – that is, information acquisition – will predominantly be systems-driven in the MASS development or adoption journey. Across all five instruments, information acquisition will be performed exclusively by the vessels' systems between 50% and 80% of the time. Between 17% and 25% of the time, this function will be shared between mariners and the vessels' systems. It will, however, only be exclusive to mariners less than 17% of the time.

Expressed differently, if the total duration to full autonomy from lowest were to be represented by the value 100%, information acquisition can be expected to spend the least amount of time (under 17%), being done by seafarers; then a little bit longer (17% to 25%) being shared; and finally, most of the time (50% to 80%) being performed by the vessels' systems. This means that information acquisition could reach full autonomy as early as 20% into the journey (100% minus 80%).

The second function – that of information analysis – would spend most of the time (25% to 67%) in this journey being systems driven. Exclusive mariner-driven information analysis seems to be the second most dominant of the time (at between 17% and 50%), while the shared mode would be the shortest (17% and 33%). This means that information analysis could reach full autonomy as early as 33% into the journey (100% minus 67%).

Between information analysis and information acquisition, the former would therefore more likely be the quicker one to reach full autonomy. Its systems would therefore be the first or the fastest to be innovated upon.

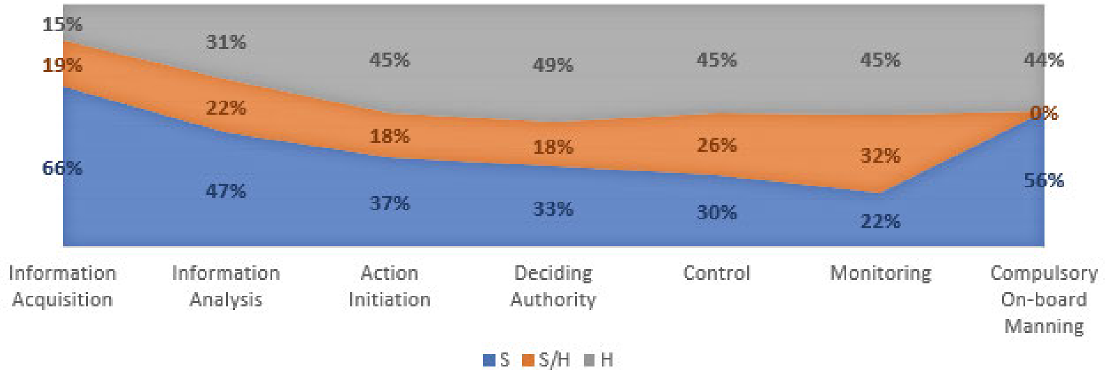
Clearly, the approach used to explain the transition from human-driven (least autonomy) to systems-driven (full autonomy) modes of performing the first two functions is complex. To simplify the explanation, a combination of the five area plots in Appendix C was done. Ideally, the resulting plot should exhibit a similar shape as the five instruments, which will be immediate proof of convergence or agreeability in the approach of converting functions or tasks in a ship from being fully mariner-driven to fully ship systems-driven. The combination is done by taking a simple mean for each cell across all five instruments and entering the results in Figure 2(c) below. Figure 2(d) is the area plot of Figure 2(c) – the average instrument.

Figure 2: A combination of the graphical visualizations of Tables 3, 5, 7, 9 & 11

(c)

	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
H	15%	31%	45%	49%	45%	45%	44%
S/H	19%	22%	18%	18%	26%	32%	0%
S	66%	47%	37%	33%	30%	22%	56%

(d)



Quite apparent and requiring no extensive explanation, the shape of Figure 2(d) exhibits similar attributes expressed in the fourth paragraph of this subsection which explains the overall observation of the area plots in Appendix C (first paragraph on Page 68). This affirms fully, the convergence of the various classification societies' approaches in converting functions from being purely mariner-driven to ultimately, being fully systems-driven.

From left to right, the pace of automation seems to decrease. Ship monitoring is the slowest to be made fully autonomous. This is because it remains performed by humans for 45% of the time (grey) in the MASS adoption journey; then spends a massive 32% of the time in transition as a shared task between mariners and systems (orange) before finally being fully handed over to the ships' system in the last quarter of the journey (blue at 22%). This contrasts with information acquisition, which was explained earlier in the seventh paragraph of this subsection (third paragraph on Page 68) albeit for Table 5. Deciding authority, action initiation, and vessel control lie somewhere in between. They are also slow to be transitioned from being mariner-driven, but extremely quick in the transition phase of being shared.

Finally, observed in Figure 2(d) is that mariners will remain onboard the vessel until just about halfway (44%) in the MASS adoption journey (theme 7). Thereafter, there will be no compulsory requirement for them being onboard a vessel. This marks the turning point of mariner employment as will later be fully explained in sub-section 4.3.2.

4.2.3 Systems likely to be Automated and their Sequence

The analysis in sub-section 4.2.2 – that of Figure 2(d) in particular – and the third assumption in section 1.9, set a platform for establishing the potential sequence that can be expected in the development and introduction of autonomous systems on merchant ships. An assumption has already been made that the wave of automation will start from the left of the tables: that is theme 1 (information acquisition), to the right of the tables: that is theme 6 (monitoring). But what systems in a vessel are associated with these functions, one might ask. Below, an attempt to single these out is made.

Information acquisition systems include sensors and audio-visual equipment. These types of electronic equipment already exist widely, but further development may be required for adaptation to the harsh sea environment with prolonged maintenance intervals. Special sensors for specific applications in the sea may be required as well. Advanced video capturing equipment to provide high-resolution images in all weather conditions and at various times of the day. The radar system, forming part of information acquisition for situation awareness, will also be amongst the initial systems needing autonomy innovation.

Information analysis, decision making, and action initiation are functions that will require complex computing capabilities first and foremost, followed by efficient distribution of that information. Information and communications technology (ICT) equipment should be the next critical, therefore, to be innovated for successful MASS implementation. ICT equipment generally includes computing equipment, and connectivity equipment for efficient data and information processing and transfer.

Control functions would be next for innovation. These will include the mechanical, electrical, and electronic parts of the vessel. These systems will need to be innovated for reliability, efficiency, durability, and minimum need for redundant systems.

Lastly, monitoring systems will become the focus. This will span electronics, advanced audio-visual, and virtual environment technologies. Replications of the bridge at an RCC offering as close to a replica or even better of the actual environment should be the target.

4.3 Impact on mariner employment – Graphical representation

Up to this point, different degrees of autonomy have been explored, with each accompanied by the expected shift in mariner employment. Sub-section 4.2.1 concluded by expressing the potential magnitude of employment reduction when full autonomy is reached. These numbers ranged from 90.5% to 95.2% depending on the number of ships supported by a team of RCC-based operators. Due to the novelty of the MASS technology, and the lack of properly quantifiable datasets, it is challenging to produce detailed numerical data leading to these predicted employment reduction potentials. This subsection aims to partially bridge that gap by merely graphically expressing the trends that will lead to these predicted numbers.

Figure 3 below shows time on the horizontal axis, increasing from left to right. In the vertical axis are two variables: the number of merchant ships (both autonomous and conventional) and seafarer employment. Therein, curves, texture-filled and solid-filled circles can be found. The circles represent the saturation of the type of ship technology (conventional or MASS) in the market at a given time. They give more information about the curve they are next to – either **CS** or **AS**. Their magnitude is expressed by the fill, and not by any of the 3 axes.

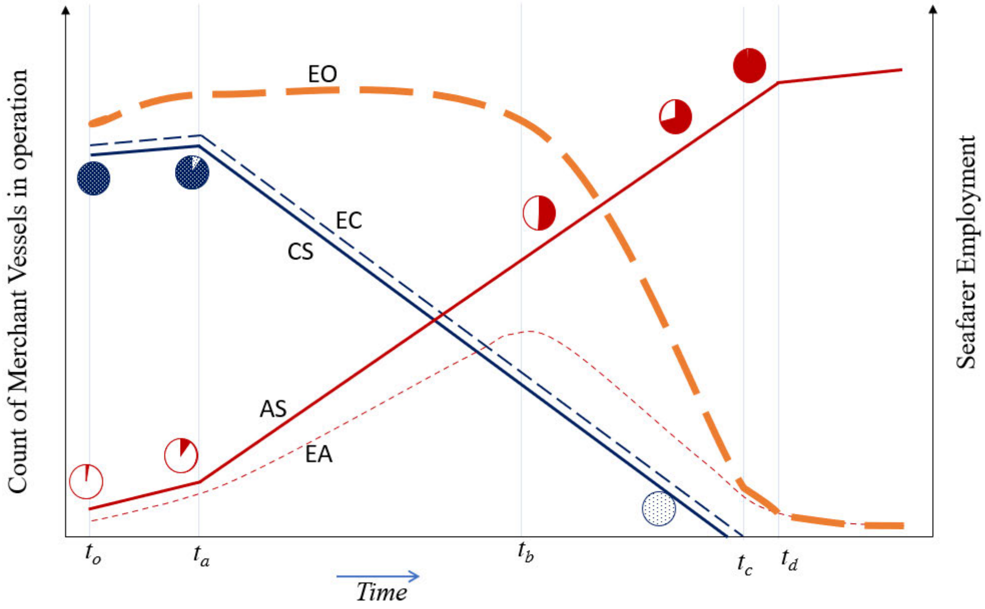


Figure 3: Evolution of Global Mariner Employment vs. Merchant Ship Saturation changes

Curve **AS** shows the count of **<u>a</u>**utonomous surface merchant **<u>s</u>**hips, and curve **CS** the count of **<u>c</u>**onventional merchant **<u>s</u>**hips. The solid-filled and the texture-filled circles next to curves **AS** and **CS** respectively are associated with the saturation of those ship types in the market. Curve **EA** shows the magnitude of **<u>e</u>**mployment on **<u>a</u>**utonomous ships, and **EC** shows the magnitude of

employment on **c**onventional ships. Finally, curve **EO** is the **o**verall **e**mployment magnitude of seafarers in the market – the sum of EA and EC. In the text below, the notation used to navigate the plot below will be $t_{\dots}$ for a point in time and **(CurveName, $t_{\dots}$)** for a point in time on a particular curve.

4.3.1 Employment on Conventional and Autonomous Ships Post MASS Introduction

At some point, say t_0, the market will start seeing the introduction of low autonomy MASS (AS, t_0). From this point onward, the saturation of autonomous vessels in the market will start as, will mariner employment on those vessels (EA, t_0). As established earlier in subsection 4.2.1, paragraph 5, there will be little to no reduction in mariner employment count per autonomous vessel for these low-autonomy MASS. The rates of increase of autonomous vessel counts in the market and employment increase on them during the period t_0-t_a will therefore very closely mimic each other; that is, a linear positive correlation will be exhibited.

For conventional ships, the market will start from a fully saturated state (CS, t_0), but this saturation, diluted by the autonomous ship introduction, will immediately start decreasing despite the count of conventional merchant vessels on the market continuing to increase for a while longer during period t_0-t_a. The continuation on increase in the count of these merchant vessels will be due to two reasons: First, conventional vessels on order as at t_0 will continue to be delivered for some time beyond t_0; and second, not every ship owner will immediately place an order for an autonomous ship. There will be a period of close observation as confidence is in autonomous vessels. Mariner employment on these conventional merchant marine vessels will also continue to very closely mimic (a positive correlation) that of the conventional ship count increase. It is assumed that ship demolition will not majorly impact the employment curve, largely because trade will be growing at the same time (see the first assumption in section 1.9).

At some critical point t_a, enough confidence will have been gained from earlier MASS such that two things will start to happen: First, there will be a significant uptick in MASS order and delivery, increasing the count thereof in the market (AS, t_a-t_d); and second, the levels of autonomy in those ships will be incremental resulting in increased autonomy saturation in the market for the period t_a-t_d. By the time point t_d is reached, full autonomy saturation in the market will be reached. At full autonomy saturation, only fully autonomous ships – the goal for all regulatory instruments studied – will be deployed and servicing the maritime industry globally.

It should be noted that the autonomous vessel-count growth curve **AS** in the period t_a-t_d is presented as being simply linear just to depict the notion of growth, but it could take any shape: Linear, logarithmic, or even a polynomial with periodic declines. The true shape will depend on many variables including market growth, vessel (both conventional and autonomous) demolition rates, and other latent variables covered by the third assumption in section 1.9.

A highlight of the decreasing gaps between the solid-filled circles along the **AS** curve for the period t_a-t_d. This attempts to exhibit that with a simplified linear autonomous ship count increase, more high-autonomy ships and less low-autonomy ships will be built as time advances. This will result in autonomy saturation increasing in a non-linear manner – possibly exponential.

Seafarers employed for these autonomous ships (curve **AE)** in the same period t_a-t_d will exhibit two notable phases: an employment increase phase, t_a-t_b; and an employment decrease phase t_b-t_d. In the former phase, more mariners will be employed following the uptick in autonomous vessel orders and delivery. However, although a positive correlation will still be seen between **AS** and **AE**, it will become weaker. The weakness will be a result of the increasing saturation of autonomy in the field. The increase in seafarer employment will grow slower than that of the count of MASS. At some point t_b, the autonomy saturation in the field will start to cause a negative correlation between **AS** and **AE** – the turning point on seafarer employment on such vessels as established earlier (sub-section 4.2.1 par. 17 – discussion of the **M** region).

Beyond point t_b, fewer mariners will be employed per vessel. The negative correlation will very likely become stronger as time moves farther away from point t_b. This is because it is assumed that demolition of earlier generation MASS will either already be taking place or just starting. Replacements for those demolished first-generation lower-autonomy MASS will presumably be higher-autonomy MASS.

Meanwhile, on the conventional vessel market side, point t_a will have triggered a new reality for a conventional ship: the ceasing of its orders and finalizing the builds for the last deliveries. Beyond point t_a, there will be an extremely reduced order book for conventional ships if it does not cease to exist altogether. Overall, the major and notable trend will be a reduction in counts of conventional vessels as a result of demolition and loss through other means. This is visualized through the negative gradient of curve **CS** for the period t_a-t_c in Figure 2. Similar to the **AS** curve, this curve is being simplified to being linear, while in reality, it may be any polynomial. The same assumptions here are being made.

Notable in this case as well, is that accompanying the **CS** curve is the decline in the saturation of the conventional ship in the market. While this saturation decline does not imply much for the employment numbers accompanying the **CS** curve, it will have significance for the overall mariner employment market discussed in the next subsection. This is because, throughout the period t_a-t_c, the amount of employment loss per lost ship is relatively constant but high (at the average of 21 members per crew, per ship on average). This significance will be discussed further when curve **EO** is discussed in the subsequent sub-section. At point t_c, conventional ships cease to exist and so does employment on them.

Curve **EC** continues a positive correlation to the **CS** curve for the period t_a-t_c. One of the factors that could be expected to impact this gradient for labour could be productivity and efficiency fluctuations. But it is believed that this would be minimal because it would most likely happen at a ship or even company level, but minimum safe manning requirements could still prevent certain labour reductions.

The period beyond point t_d is a period that will be influenced by the dynamics of the market. For this research, it is assumed that at this point, with only fully autonomous ships in operation, further fleet growth will move back to being dictated by market demand – a growth trend exhibited before point t_a for the **CS** curve. Worth noting, however, is the assumption that the count of **AS** at point t_d and beyond will be higher than the count of **CS** at point t_a and prior. This is because of the first assumption covered in sub-section 1.9 that maritime trade will continue to grow according to the UNCTAD (2020).

4.3.2 The Overall Seafarer Employment Curve Post MASS Introduction

Now that curves **AS** and **CS** are understood, and it has been established how they will impact mariner employment as depicted in curves **EA** and **EC** respectively, the focus now moves to describing the remaining curve – curve **EO** – for the overall impact on mariner employment.

At any point, curve **EO** shows the sum of curves **EA** and **EC**, and it represents the overall global employment of seafarers.

For period t_0-t_a, **EO** shows an increase in the overall employment of mariners. This is no surprise because as covered in the preceding sub-section, curves **EA** and **EC** increase in this region. Their sum also increases.

For period t_a-t_b however, the overall impact of the uptick in MASS adoption at point t_a starts to become apparent. The **EO** curve loses the huge positive gradient or growth trend it had in the previous period. This gradient tends very close to zero, implying no growth in mariner employment globally. The nearly zero gradient curve is a sum of the increasing and decreasing **AE** and **AS** curves. respectively.

It is plausible to expect zero growth in this region because any employment growth due to increased market demand for freight services will be negated by the smaller number of mariners due to new autonomous ships introduced. Alternatively, the plausibility of zero growth can be explained by looking at the saturation levels of autonomy in the market. In the previous subsection, it was explained that with a linear increase in autonomous ship count in the market, the saturation of autonomy would increase at a much faster, potentially exponential rate. Also, it was explained that the antitheses of that behaviour was neither the case nor expected for conventional ships during the same period due to a flat headcount loss of around 21 mariners on average per conventional ship lost or demolished.

At point t_b, the inception of a steep decline is observed for curve **EO** as a result of the sudden negative gradient of curve **AE**. In this region, continued declining employment numbers on conventional ships due to ship demolition and other losses; and incremental declines in employment on MASS due to incremental autonomy saturation in the market result in smaller numbers added together as time advances, causing the observed sharp decline.

At point t_c, where conventional ship employment ceases to exist following the cessation of the existence of merchant conventional ships shortly beforehand, curve **EO** meets curve **AS** which becomes, at this point (t_c), the only source of employment. On reaching point t_d, full saturation of autonomy is reached and seafarer employment beyond this point is only RCC based and minimal. Mariners are no longer referred to as crew members, but as operators, and they now periodically monitor multiple vessels on demand. The region t_c-t_d is expected to be where the predicted values of 90.5% to 95.2% reduction in seafarer employment manifest, as discussed in the last paragraph of subsection 4.2.1.

Chapter 5: Conclusion & Recommendations

5.1 Conclusion

This dissertation set out to establish the potential impact that the introduction of MASS could have on mariner employment globally. In the first chapter, the need for and importance of the study were highlighted, as well as the overall approach that would be assumed to answer the critical question.

In the second chapter, the study moved on to extensively explore current literature covering various aspects of the merchant shipping business. Covered therein were a brief history of the sector, parties involved in the sector, the composition of the merchant marine fleet as well as typical compositions of the crew that operates it. Issues related to mariners were explored, which are seminal to the ambition for a move to MASS. MASS was also covered – its description, state of the art of its development, challenges that it will introduce in the sector, and, in general, the impact of automation on the labour force in various industries. The chapter concluded by highlighting how there may be a misalignment in the direction of the maritime sector's shipowners and policymakers around the world. Policymakers see the maritime industry as a potential source of various jobs, amongst which are mariner occupations, while the industry seeks to eliminate that category of jobs.

Chapter three presented data collected both on MASS and mariner employment after presenting the methodology used to collect it. Data collected on MASS was presented, rearranged, and standardized to enable cross-comparative analysis. On MASS, the data collected was extracted from a randomly selected sample of MASS classification documents. The documents covered proposed degrees of autonomy and what each degree entailed. The data collected on mariner occupations covered typical occupations onboard a vessel and duties associated with them.

In Chapter four, everything was brought together in an in-depth analysis that linked MASS degrees of autonomy's system- and human-performed tasks with various occupations on a ship. Before this, however, a check for alignment in the approaches by the various classification instruments was checked to establish alignment in MASS classification. Overall, massive alignment in the approaches was observed, which built a solid platform for inference of a reasonable expectation towards a collaborative and synergetic approach (direct or indirect) in successful MASS development and implementation. No varied or divergent approaches were found, and there was, therefore, no need to draw on lessons from other modes of transport.

Various occupations likely to be eliminated, substituted, or moved to an RCC were identified for each degree of autonomy. It was approximated that by the time the market is fully saturated with high-autonomy MASS, well over 90% of the peak mariner employment since the debut of merchant MASS could be eliminated. The only remaining jobs could be those of the master, the chief engineer, and two other employees: one from the deck department and the other from the engine room department. All these four would be based at an RCC.

It was, however, established that the reduction in mariner employment would not be linear. The major drop in employment would only present itself after the saturation of autonomy reached a 50% level in the market. Preceding this, a short period of slowed growth in mariner employment would be seen as MASS was initially introduced, which would be followed by a prolonged period of no growth initiated by a major adoption of MASS by the market. Both phases would span the period leading to 50% of MASS saturation on the market.

Finally, what could not be established in the study were the timelines for those developments. The timeline was never intended to be studied in this research work but has presented itself as a major point of interest to finalize the picture.

5.2 Research Question and Sub-questions: A coverage reconciliation

Specific sub-questions were asked in sub-section 1.5, answering which would lead to the possibility of being able to answer the major question of this dissertation. Those questions are re-visited below to ensure it is clearly communicated which have been and which have not been answered.

Under MASS, the question about proposed levels of MASS has been answered in Tables 2, 4, 6, 8, and 10 spread out through chapter 3, sub-section 3.3. The question about the extent to which these proposed levels of degrees of autonomy were convergent was answered in the detailed analysis part of the dissertation – chapter 4. This cross-comparison would have otherwise been challenging without the transformation to standardized formats in Tables 3, 5, 7, 9, and 11. Convergence was proven in chapter 4, subsections 4.2.1 and 4.2.2. The last sub-question concerning divergent approaches did not have to be dealt with as there were hardly any. It was discovered that overall, there was alarming agreeability in the approaches towards MASS development and introduction.

Under mariner occupations, the quest for understanding mariner jobs was fulfilled in chapter 3's sub-section 3.4. The organization of a merchant vessel's crew was explored from the ship's master to the lowest rating. Each occupation's role and duties were explored. The question about which of these occupations would potentially be affected by the introduction of MASS was answered in the analysis chapter's sub-sections 4.2.1 and 4.2.3. The former identified the occupations that would be affected, and the latter rounded it off by estimating how many would be impacted. The last question about how much different this impact would be across different vessels was never focussed on because sub-section 4 in chapter 2 (i.e. 2.4) showed us that the crew was not so different across different merchant vessel types, having stabilized to about 20 members per crew.

Having dealt with all of these sub-questions, the main research question could be answered. It was established that the overall impact of the introduction of MASS on mariner employment would be one that would so much depend on the different phases of MASS development and adoption, as well as the saturation of autonomy in the market. Major milestones or turning points were identified as major adoption of MASS by the market, reaching 50% of autonomy saturation, and finally, reaching 100% saturation of autonomy. At this last milestone, employment could be reduced by 90%.

5.3 Recommendations

5.3.1 Recommendations for Shipowners

Quite apparent in the study is the massive alignment in the approaches to the introduction of MASS. There is therefore no recommendation in that aspect. However, a great benefit from that is the prospect of a joint effort in everything concerning MASS development and introduction. This will help in many ways including but not limited to:

- Faster realization of the MASS journey milestones and notable contraction of autonomy saturation duration.
- Decreased costs in the development of systems by adopting a divide and conquer approach on a global scale in autonomous ship systems development.
- Minimize the need for retrofits at a later stage to cater to systems developed for un-aligned approaches.

It is therefore recommended that various organizations strive for joint and collaborative development towards MASS implementation. This could be done by establishing a global body of knowledge in MASS development under the IMO, or a similarly established or matured and far-reaching organization.

5.3.2 Recommendations for Policymakers

Quite apparent as well through evidence presented is that several policymakers are looking towards the maritime sector's seafarer employment as one of the major sources of employment. This might not materialize based on the investigations and findings in the preceding chapters. The seafarer employment increase might not be long-lived. The response to the big mariner shortage covered in chapter 2 will possibly be successfully responded to by MASS introduction. A no-growth regime may then follow and be extensive before employment numbers rapidly plummet to extremely low levels, and remain there well into the future.

It is therefore recommended, in this regard, that policymakers take note of the evolution in the maritime sector's employment trends. The outlook currently shows that mariner employment should be cautiously placed under high-growth potentials for job creation, if at all.

The second recommendation in this regard is for policymakers to closely watch the development and adoption of MASS. This can be done by looking at the order books for autonomous ships and conventional ships for major shifts in innovation and employment trajectory such as those at t_0 and t_a in Figure 3.

The third recommendation is for policymakers to keep an eye out on various IMO instruments such as the SOLAS, and STCW for amendments to accommodate MASS. These will, however, be weak indicators of development status and should not be used in isolation.

5.3.3 Recommendations for training institutions

As the takeover by the ships' systems starts, most functions (and ultimately jobs) will possibly be replaced while others get shared between mariners and these systems. The maritime training and education sector may not be adequately equipping its graduates for this possible future.

It is therefore recommended for these institutions to also keep a close watch on the developments in the sector. While this may not initially (leading t_0) be the case, they will, at some point, be expected to produce graduates with certain new competencies to help them cope with MASS. This competence will evolve with the increase in the saturation of autonomy in the market – that is, as more systems become autonomous and as more autonomous ships are rolled out to the market.

5.3.4 Recommendations for legislators

It is recommended that maritime legislation bodies in nations that have ratified various IMO instruments keep an eye out on the various changes being recommended, and those that will eventually be recommended. Local legislation based on these instruments will be impacted. Instruments and regulations to keep an eye on are the COLREG, the STCW, and SOLAS. Safe Manning Requirements.

5.4. Further Research

The findings of this research certainly assist in the foresight of labour and business planning for those in the maritime industries, or any other interested body – especially policymakers. The main gap however that this work does not close is the issue of timing. Timing on the evolution of employment will depend on the rate of technological advancement towards MASS. Other transport industries, having gone through (the aviation industry) or making strides (the automotive industry) on autonomy, it may be possible to research possible timelines for the maritime industry to introduce MASS and develop to full autonomy.

It is therefore recommended that a study be embarked on, to help establish possible timelines for MASS introduction to the market (t_o) and mass adoption (t_a) and finally reaching 50% saturation in the market (t_b)

The second recommendation is for similar studies as this dissertation to be taken, but with a different methodology and, or, data sources, the outcomes of which can be compared with these.

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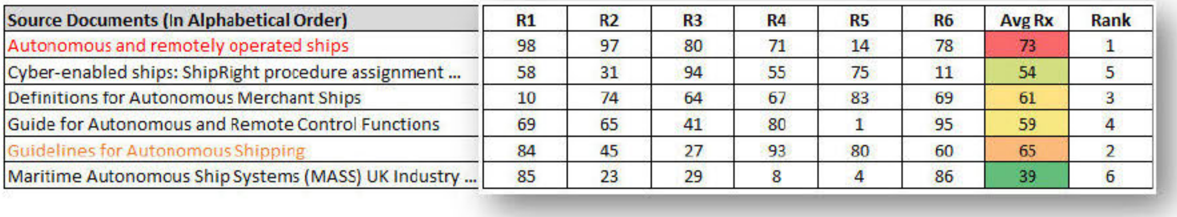
Appendices

Appendix A: MASS Classification Instruments

Appendix A1: The instrument Population – Existing Classification Documents by ICS Members

Title	Doc. Type	Regulatory or Classification Institution / Organization / Body	Year
Autonomous and remotely operated ships	Class Guideline DNVGL-CG-0264	Det Norske Veritas Germanischer Lloyd	September 2018
Cyber-enabled ships: ShipRight procedure assignment for cyber descriptive notes for autonomous & remote access ships	A Lloyd's Register guidance document - v.2	Lloyd's Register	December 2017
Definitions for Autonomous Merchant Ships	Draft Document - v.1	Norwegian Forum For Autonomous Ships (NFAS)	October 2017
Guidelines for Autonomous Shipping	Guidance Note NI 641	Bureau Veritas - Marine & Offshore	October 2019
IMO takes first steps to address autonomous ships	Web Article, MSC 99	Maritime Safety Committee, IMO	May 2018
Maritime Autonomous Ship Systems (MASS) UK Industry Conduct Principles and Code of Practice	A Voluntary Code - v.5	Maritime UK	October 2021
Guide for Autonomous and Remote Control Functions	Guide	American Bureau of Shipping (ABS)	July 2021

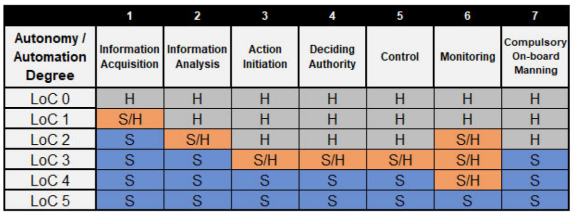
Appendix A2: The random selection of 4 out of 6 Instruments, excluding the pre-chosen IMO classification document using RANDARRAY()



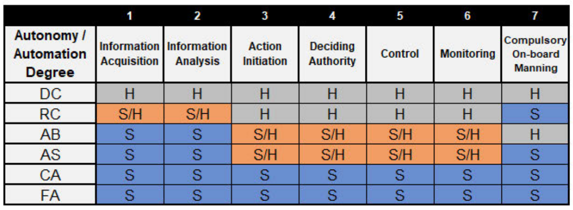
Source Documents (In Alphabetical Order)	R1	R2	R3	R4	R5	R6	Avg Rx	Rank
Autonomous and remotely operated ships	98	97	80	71	14	78	73	1
Cyber-enabled ships: ShipRight procedure assignment ...	58	31	94	55	75	11	54	5
Definitions for Autonomous Merchant Ships	10	74	64	67	83	69	61	3
Guide for Autonomous and Remote Control Functions	69	65	41	80	1	95	59	4
Guidelines for Autonomous Shipping	84	45	27	93	80	60	65	2
Maritime Autonomous Ship Systems (MASS) UK Industry ...	85	23	29	8	4	86	39	6

Appendix B: Alternative presentation of Tables 3, 5, 7, 9, and 11

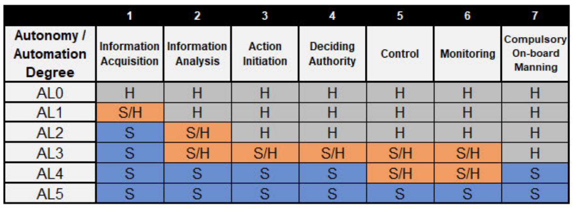
(i) Coloured representation of the tables



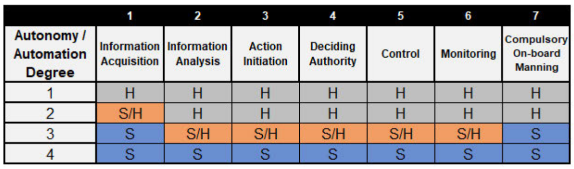
	1	2	3	4	5	6	7
Autonomy / Automation Degree	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
LoC 0	H	H	H	H	H	H	H
LoC 1	S/H	H	H	H	H	H	H
LoC 2	S	S/H	H	H	H	S/H	H
LoC 3	S	S	S/H	S/H	S/H	S/H	S
LoC 4	S	S	S	S	S	S/H	S
LoC 5	S	S	S	S	S	S	S



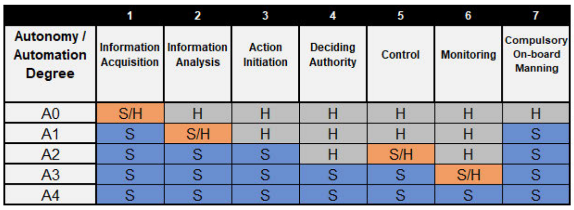
	1	2	3	4	5	6	7
Autonomy / Automation Degree	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
DC	H	H	H	H	H	H	H
RC	S/H	S/H	H	H	H	H	S
AB	S	S	S/H	S/H	S/H	S/H	H
AS	S	S	S/H	S/H	S/H	S/H	S
CA	S	S	S	S	S	S	S
FA	S	S	S	S	S	S	S



	1	2	3	4	5	6	7
Autonomy / Automation Degree	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
AL0	H	H	H	H	H	H	H
AL1	S/H	H	H	H	H	H	H
AL2	S	S/H	H	H	H	H	H
AL3	S	S/H	S/H	S/H	S/H	S/H	H
AL4	S	S	S	S	S/H	S/H	S
AL5	S	S	S	S	S	S	S

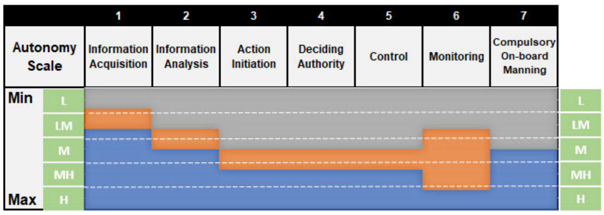


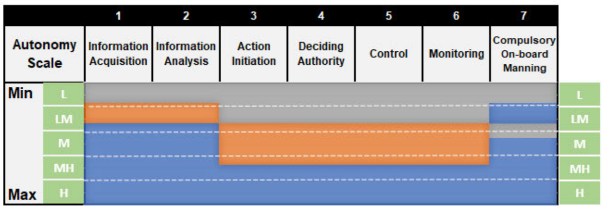
	1	2	3	4	5	6	7
Autonomy / Automation Degree	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
1	H	H	H	H	H	H	H
2	S/H	H	H	H	H	H	H
3	S	S/H	S/H	S/H	S/H	S/H	S
4	S	S	S	S	S	S	S

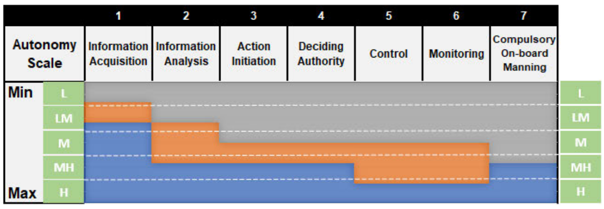


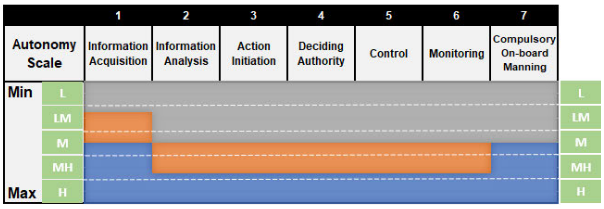
	1	2	3	4	5	6	7
Autonomy / Automation Degree	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
A0	S/H	H	H	H	H	H	H
A1	S	S/H	H	H	H	H	S
A2	S	S	S	H	S/H	H	S
A3	S	S	S	S	S	S/H	S
A4	S	S	S	S	S	S	S

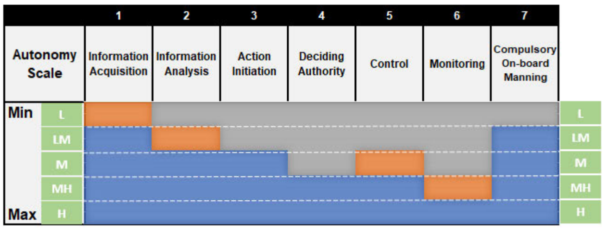
(ii) Comparison of the tables



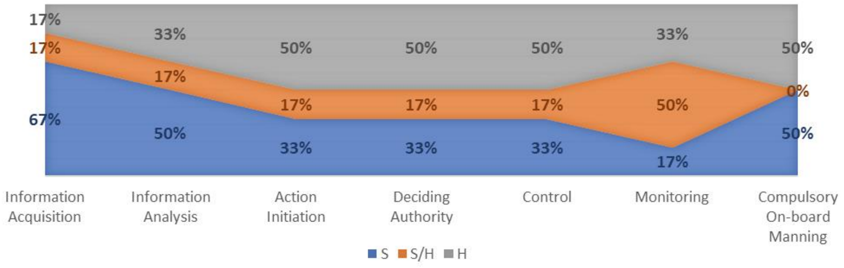


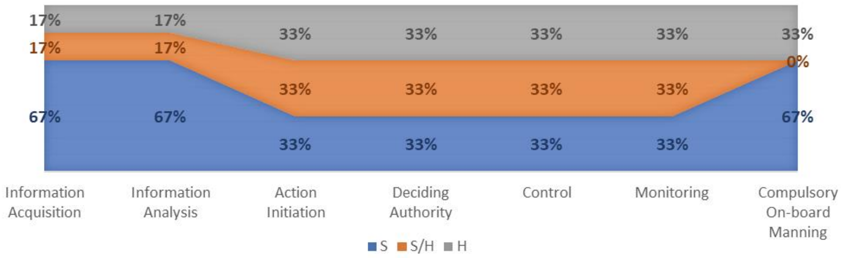


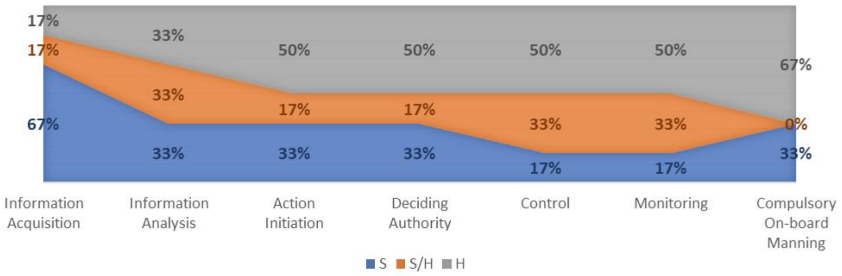


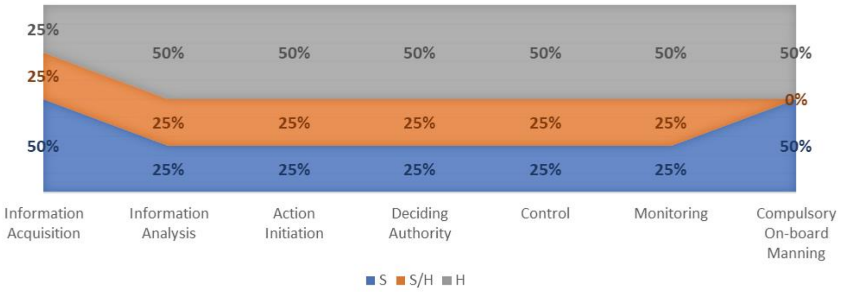


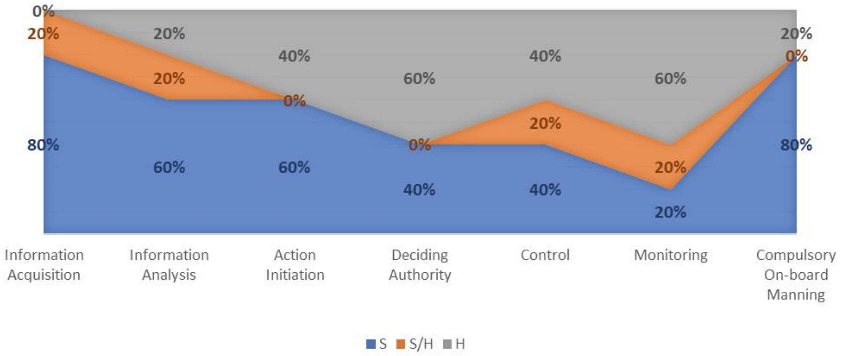
Appendix C: Area plots of Tables 3, 5, 7, 9, and 11







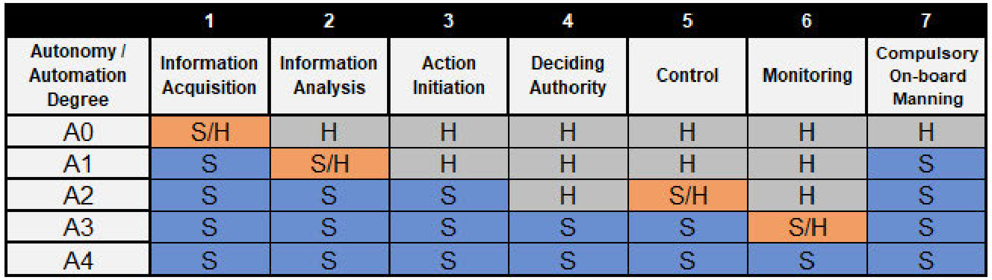




Appendix D: Transformation to grapihical representations of Tables 3, 5, 7, 9, and 11

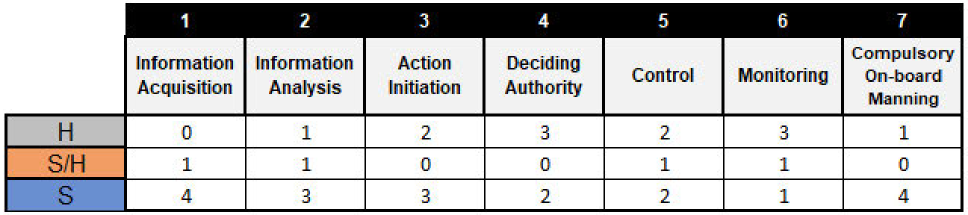
(i) Graphical visualization of Table 3

(a)



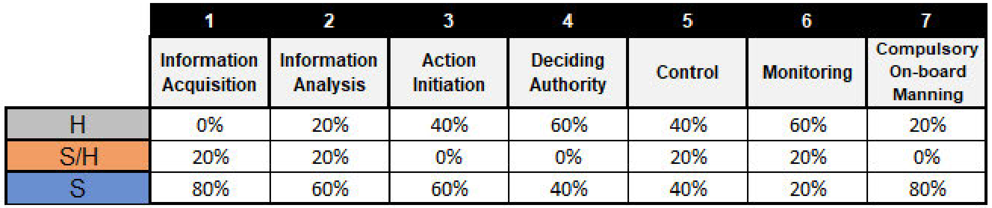
	1	2	3	4	5	6	7
Autonomy / Automation Degree	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
A0	S/H	H	H	H	H	H	H
A1	S	S/H	H	H	H	H	S
A2	S	S	S	H	S/H	H	S
A3	S	S	S	S	S	S/H	S
A4	S	S	S	S	S	S	S

(b)



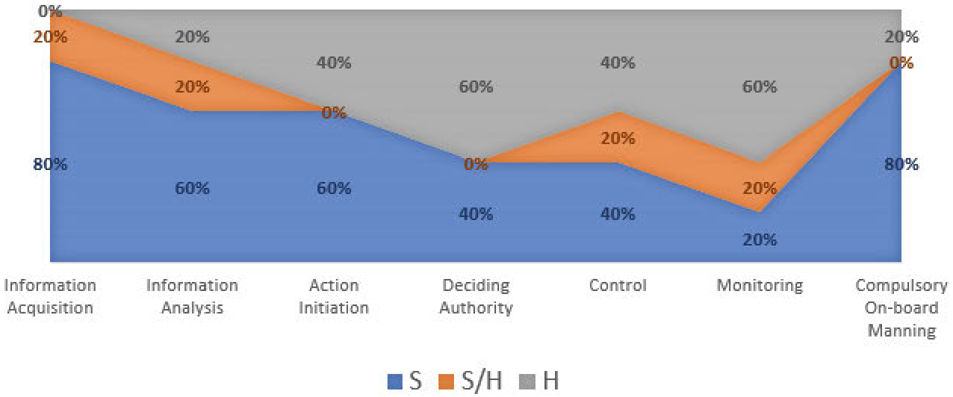
	1	2	3	4	5	6	7
	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
H	0	1	2	3	2	3	1
S/H	1	1	0	0	1	1	0
S	4	3	3	2	2	1	4

(c)



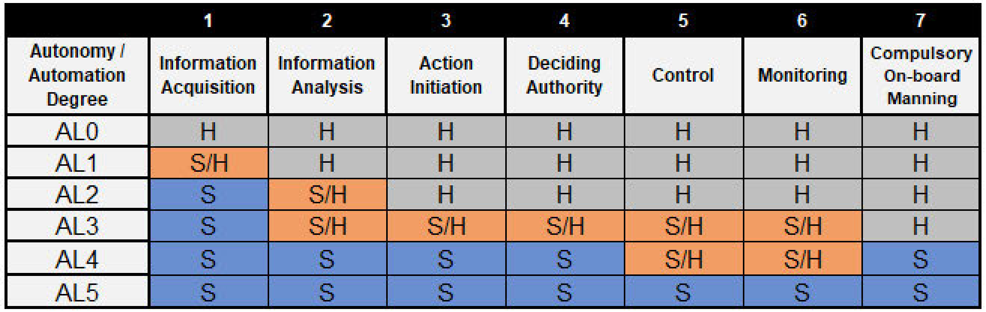
	1	2	3	4	5	6	7
	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
H	0%	20%	40%	60%	40%	60%	20%
S/H	20%	20%	0%	0%	20%	20%	0%
S	80%	60%	60%	40%	40%	20%	80%

(d)



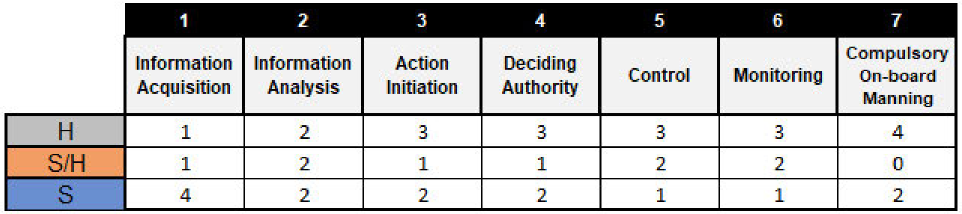
(ii) Graphical visualization of Table 5

(a)



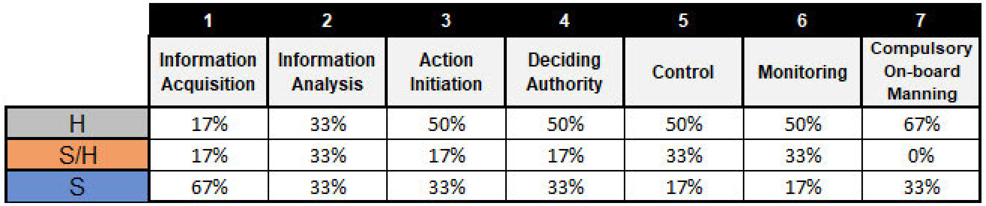
	1	2	3	4	5	6	7
Autonomy / Automation Degree	**Information Acquisition**	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
AL0	H	H	H	H	H	H	H
AL1	S/H	H	H	H	H	H	H
AL2	S	S/H	H	H	H	H	H
AL3	S	S/H	S/H	S/H	S/H	S/H	H
AL4	S	S	S	S	S/H	S/H	S
AL5	S	S	S	S	S	S	S

(b)



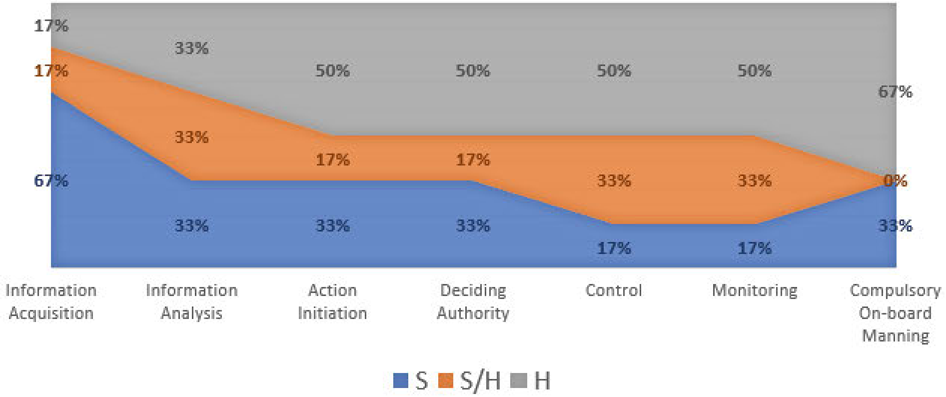
	1	2	3	4	5	6	7
	Information Acquisition	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
H	1	2	3	3	3	3	4
S/H	1	2	1	1	2	2	0
S	4	2	2	2	1	1	2

(c)



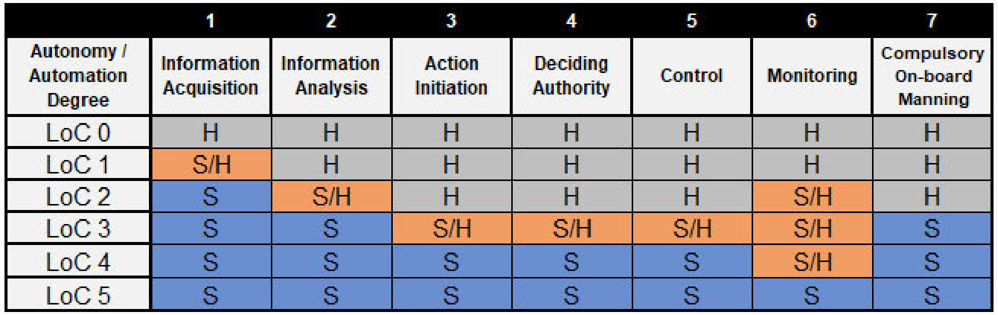
	1	2	3	4	5	6	7
	Information Acquisition	**Information Analysis**	**Action Initiation**	**Deciding Authority**	**Control**	**Monitoring**	**Compulsory On-board Manning**
H	17%	33%	50%	50%	50%	50%	67%
S/H	17%	33%	17%	17%	33%	33%	0%
S	67%	33%	33%	33%	17%	17%	33%

(d)



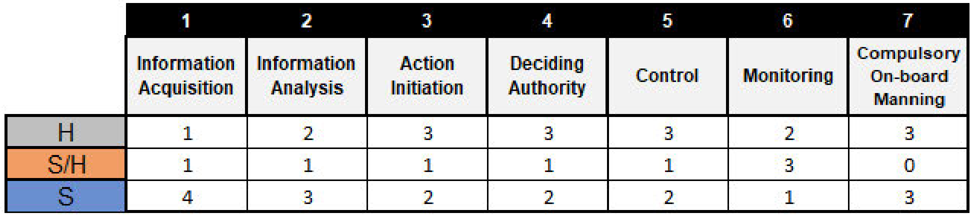
(iii) Graphical visualization of Table 7

(a)



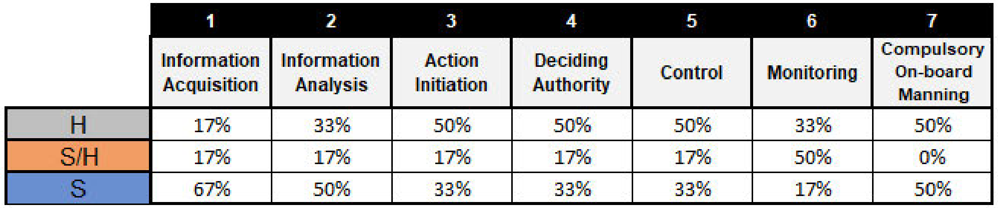
	1	2	3	4	5	6	7
Autonomy / Automation Degree	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
LoC 0	H	H	H	H	H	H	H
LoC 1	S/H	H	H	H	H	H	H
LoC 2	S	S/H	H	H	H	S/H	H
LoC 3	S	S	S/H	S/H	S/H	S/H	S
LoC 4	S	S	S	S	S	S/H	S
LoC 5	S	S	S	S	S	S	S

(b)



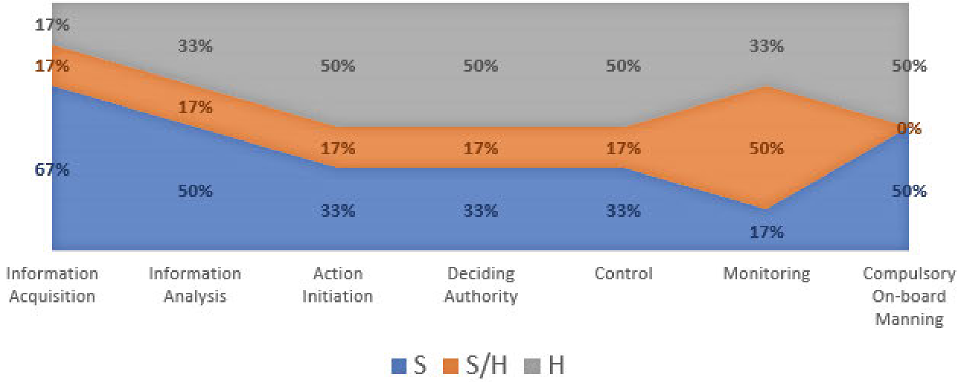
	1	2	3	4	5	6	7
	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
H	1	2	3	3	3	2	3
S/H	1	1	1	1	1	3	0
S	4	3	2	2	2	1	3

(c)



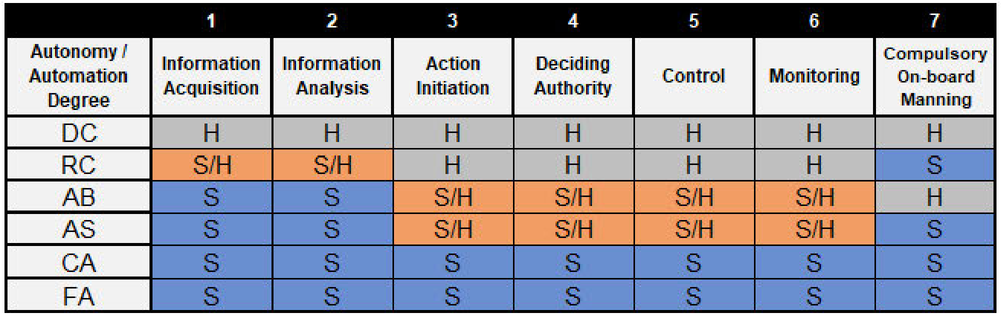
	1	2	3	4	5	6	7
	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
H	17%	33%	50%	50%	50%	33%	50%
S/H	17%	17%	17%	17%	17%	50%	0%
S	67%	50%	33%	33%	33%	17%	50%

(d)



(iv) Graphical visualization of Table 9

(a)



Autonomy / Automation Degree	1 Information Acquisition	2 Information Analysis	3 Action Initiation	4 Deciding Authority	5 Control	6 Monitoring	7 Compulsory On-board Manning
DC	H	H	H	H	H	H	H
RC	S/H	S/H	H	H	H	H	S
AB	S	S	S/H	S/H	S/H	S/H	H
AS	S	S	S/H	S/H	S/H	S/H	S
CA	S	S	S	S	S	S	S
FA	S	S	S	S	S	S	S

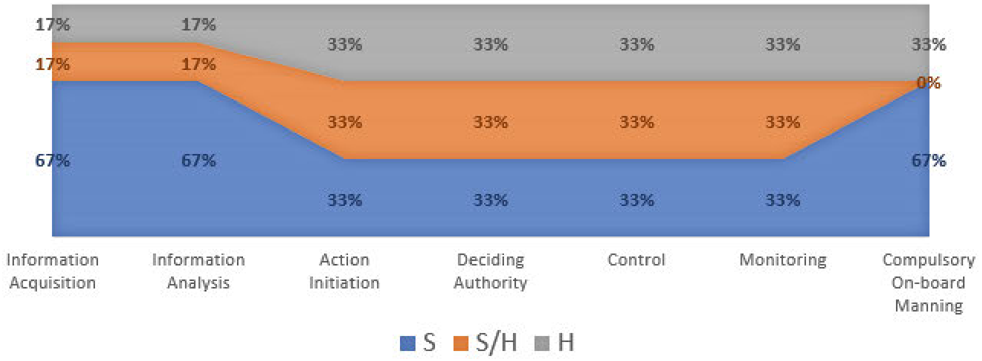
(b)

	1 Information Acquisition	2 Information Analysis	3 Action Initiation	4 Deciding Authority	5 Control	6 Monitoring	7 Compulsory On-board Manning
H	1	1	2	2	2	2	2
S/H	1	1	2	2	2	2	0
S	4	4	2	2	2	2	4

(c)

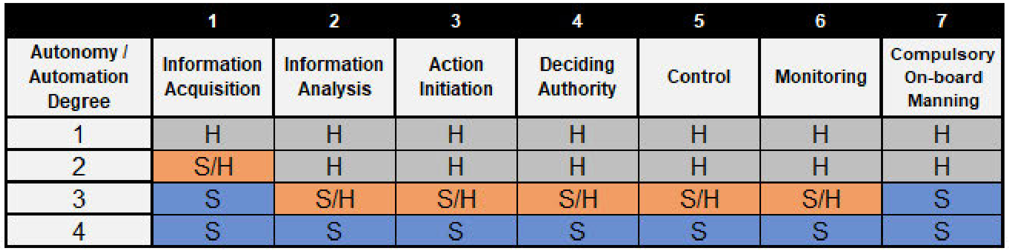
	1 Information Acquisition	2 Information Analysis	3 Action Initiation	4 Deciding Authority	5 Control	6 Monitoring	7 Compulsory On-board Manning
H	17%	17%	33%	33%	33%	33%	33%
S/H	17%	17%	33%	33%	33%	33%	0%
S	67%	67%	33%	33%	33%	33%	67%

(d)



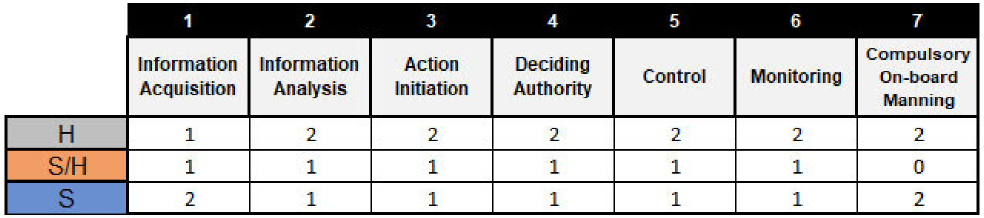
(v) Graphical visualization of Table 11

(a)



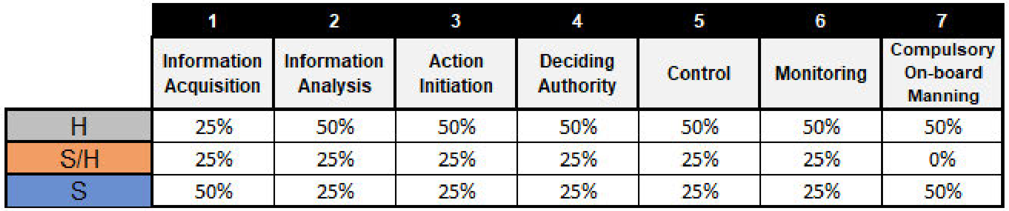
	1	2	3	4	5	6	7
Autonomy / Automation Degree	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
1	H	H	H	H	H	H	H
2	S/H	H	H	H	H	H	H
3	S	S/H	S/H	S/H	S/H	S/H	S
4	S	S	S	S	S	S	S

(b)



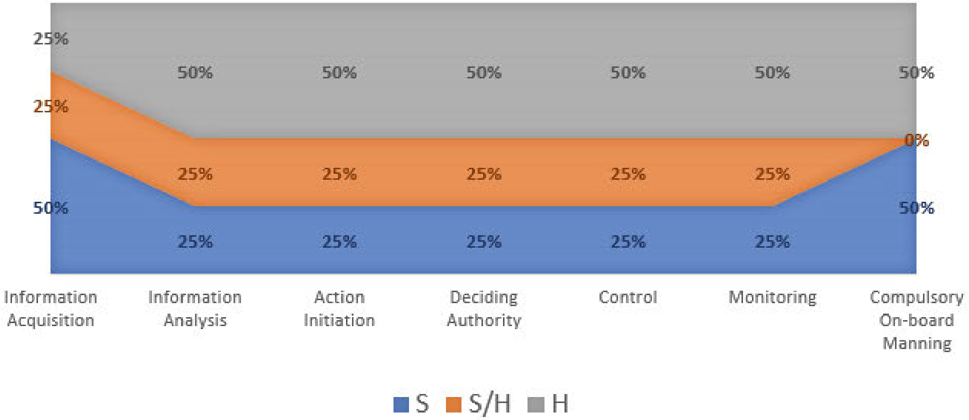
	1	2	3	4	5	6	7
	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
H	1	2	2	2	2	2	2
S/H	1	1	1	1	1	1	0
S	2	1	1	1	1	1	2

(c)



	1	2	3	4	5	6	7
	Information Acquisition	Information Analysis	Action Initiation	Deciding Authority	Control	Monitoring	Compulsory On-board Manning
H	25%	50%	50%	50%	50%	50%	50%
S/H	25%	25%	25%	25%	25%	25%	0%
S	50%	25%	25%	25%	25%	25%	50%

(d)



Appendix E: Originality Report

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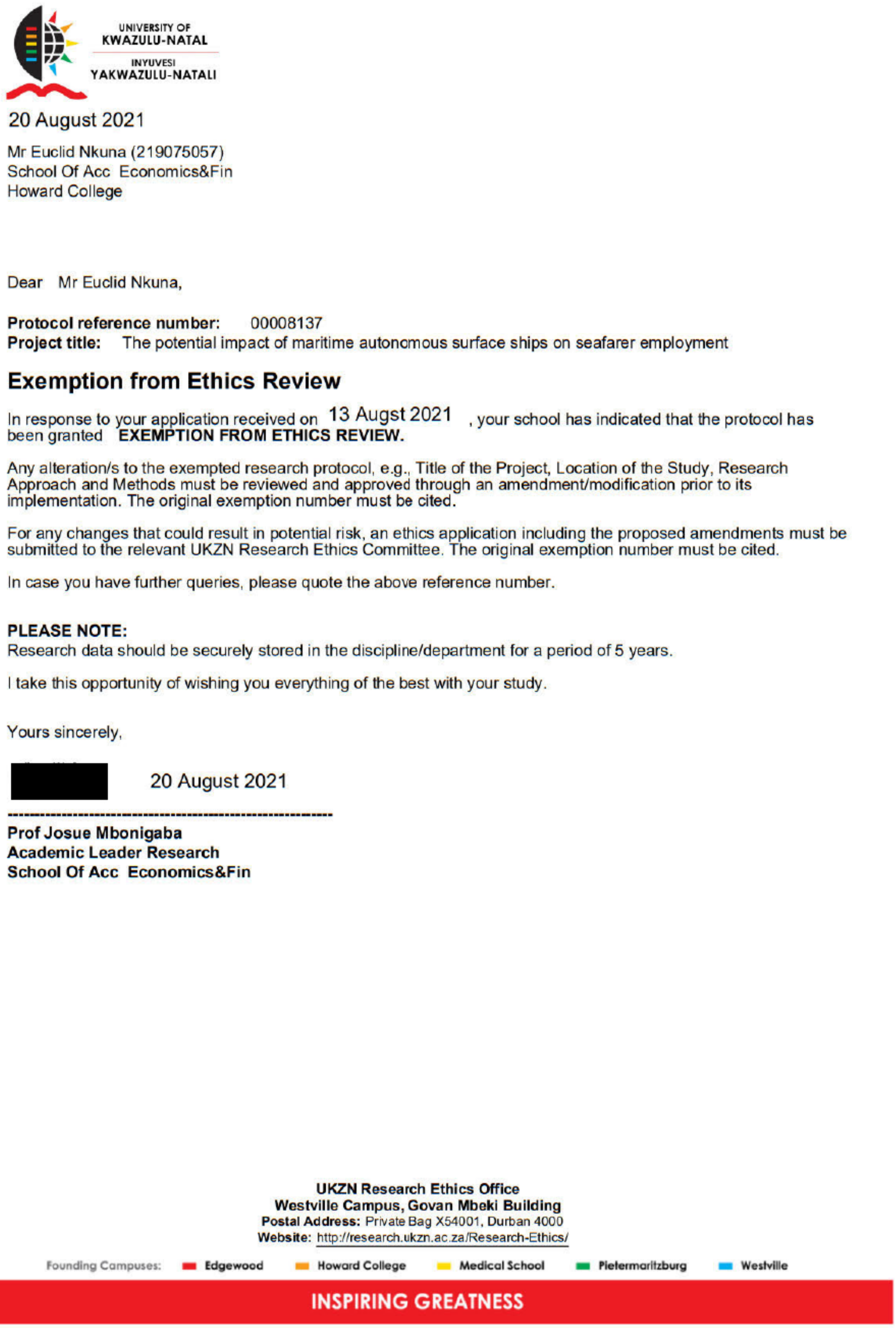
Appendix F: Ethical Clearance



UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

20 August 2021

Mr Euclid Nkuna (219075057)
School Of Acc Economics&Fin
Howard College

Dear Mr Euclid Nkuna,

Protocol reference number: 00008137
Project title: The potential impact of maritime autonomous surface ships on seafarer employment

Exemption from Ethics Review

In response to your application received on 13 Augst 2021 , your school has indicated that the protocol has been granted **EXEMPTION FROM ETHICS REVIEW.**

Any alteration/s to the exempted research protocol, e.g., Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through an amendment/modification prior to its implementation. The original exemption number must be cited.

For any changes that could result in potential risk, an ethics application including the proposed amendments must be submitted to the relevant UKZN Research Ethics Committee. The original exemption number must be cited.

In case you have further queries, please quote the above reference number.

PLEASE NOTE:
Research data should be securely stored in the discipline/department for a period of 5 years.

I take this opportunity of wishing you everything of the best with your study.

Yours sincerely,

[redacted] 20 August 2021

Prof Josue Mbonigaba
Academic Leader Research
School Of Acc Economics&Fin

UKZN Research Ethics Office
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Website: http://research.ukzn.ac.za/Research-Ethics/

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