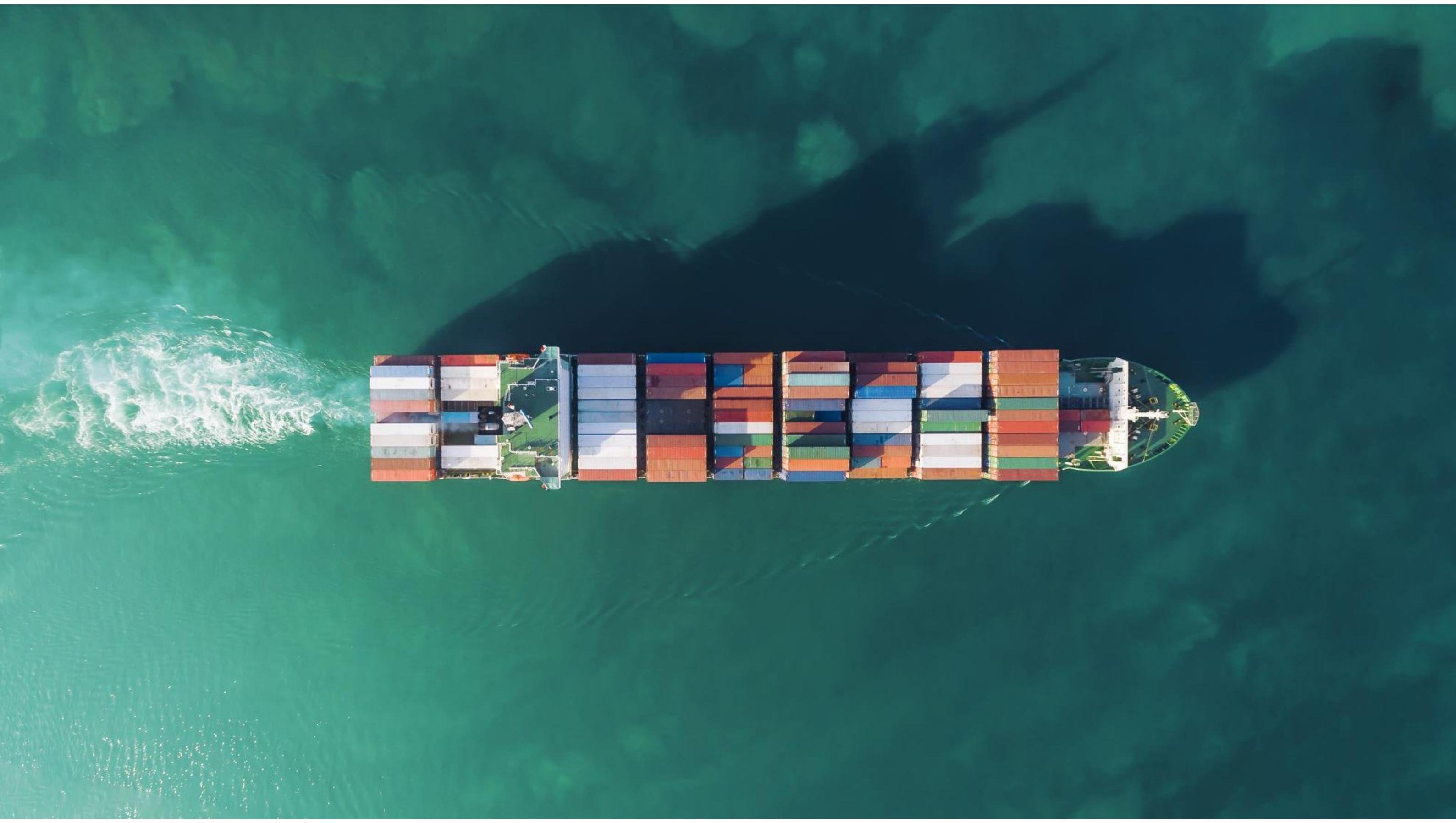
The Diffusion of Maritime Autonomous Surface Ships



Master Thesis in Management of Technology

Mariah Camara Lima Kurtinaitis Joukes
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The Diffusion of Maritime Autonomous Surface Ships

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Mariah Camara Lima Kurtinaitis Joukes

Student number: 5134242

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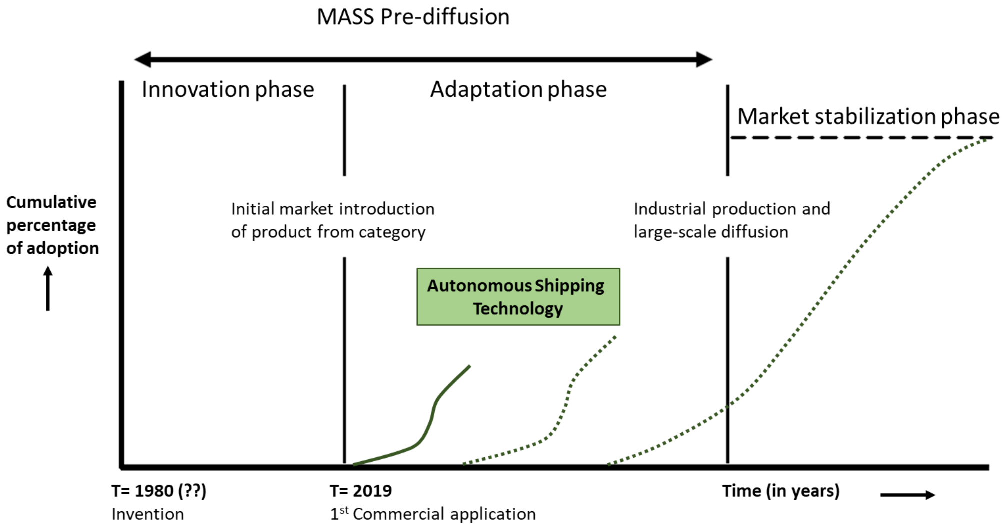
Graduation committee

Chairperson	: Dr. J. R. Ortt, Economics of Technology and Innovation
First Supervisor	: Dr. J. R. Ortt, Economics of Technology and Innovation
Second Supervisor	: Dr. M.L.C. de Bruijne, Organisation & Governance

Executive Summary

Maritime Autonomous Surface Ships (MASS) is a breakthrough technology whose development incites excitement and doubts. MASS is still in its pre-diffusion phase, which means it still undergoes adaptations to best suit the market with the ultimate goal of reaching large-scale diffusion, despite the uncertainty about the timing in which large-scale diffusion will happen. Many breakthrough technologies, however, do not reach diffusion and that is related to actors and factors affecting its Technology Innovation System (TIS). Therefore, this research aims at answering "*How can MASS reach diffusion within the maritime industry?*"



The MASS published material focuses on separate points such as safety, regulations, or the effect of crew reduction onboard vessels. However, there is no combined perspective of the actors and factors affecting MASS adoption and its consequent diffusion. This is a problem because of the interconnected nature of the factors affecting the technology, addressing one can jeopardize the other.

This study combines the analysis of the actors and factors through the Building Blocks framework (BBF) with the current MASS pre-diffusion phase, determined the by Pre-diffusion Model (PDM), and the technology introduction strategies that suit the current MASS status. It finally presents 2 pathways to MASS diffusion based on the technology introduction strategies that fit the current MASS TIS. While the framework can be used for policy matters, as well as technology companies, it is important to highlight that the pathways developed in this research focus on the managerial perspective. As an exploratory study, this report mainly relies on the use of published literature, interviews and company public declarations about MASS as data sources.

MASS combines situational awareness, decision making and action & control to enhance and possibly replace the navigator activity. This technology surfaces in a global environment where cars are becoming autonomous and the enabling technologies became cheaper and more accessible. On the one hand, MASS offers a possible solution for the crew shortage, can contribute to the maritime CO2 reduction target and promises to enhance safety. On the other hand, the lack of international regulation for the technology acts as a barrier to its adoption.

In the past few years, many companies have performed tests with MASS in short-sea and inland container vessels, harbour tugs, ferries and survey vessels. All applications share the goal of profit maximisation, either by reducing crew costs or by increasing cargo onboard. The only known commercial application so far is for survey vessels, whose crew can be removed and design can be streamlined given the absence of the accommodation. Currently, MASS is not the focus for large long-haul vessels, as the cost of the crew in these vessels has little impact on the profit margin.

MASS Influencing Factors			MASS Building Blocks
🟢 Encouraging Factor 🟠 Partial Barrier 🔴 Barrier			🟢 Present 🟠 Partially Present 🔴 Absent
Knowledge and awareness of technology	🟠	🟠	Quality & Performance
Knowledge and awareness of application and market	🟠	🔴	Cost-Benefit
Natural, human, and financial resources	🟢	🟢	Production System
Competition	🟠	🟠	Network formation & Coordination
Macroeconomic and strategic aspects	🟢	🟠	Customers
Socio-cultural aspects	🟠	🟠	Innovation Specific Institutions
Accidents and Events	🟢	🟠	Safety
Complementary Products & Services	🔴		
Operational Aspects	🔴		

MASS is currently in its adaptation phase of the PDM. In its TIS, it is visible that most building blocks are still acting as a partial barrier to diffusion, except for the Cost-benefit, which is absent and the production system, which is fully present. To ensure a more accurate description of MASS TIS, the price building block was modified to cost-benefit and safety was added as a new building block to MASS TIS. The complementary products & services building block was turned into an influencing factor because it does not affect diffusion directly, but indirectly through the cost-benefit building block.

Besides the above-mentioned Complementary products & services, the Operational aspects factor was also added to the BBF Influencing Factors to best describe MASS TIS. Natural, human & financial resources, accidents & events, and macroeconomic & strategic aspects were found to currently encourage the adoption of MASS, while the other influencing factors proposed by the BBF are partially acting as barriers to the further adoption of the technology.

Based on the building blocks and influencing factors of the BBF, niche strategies were selected from the reviewed literature to overcome the barriers to MASS diffusion. The exception was the network formation & coordination building block, for which a new niche strategy was developed to fit the MASS TIS. Finally, these strategies were combined in 2 different pathways, the institutional and the commercial pathways to achieve MASS large-scale diffusion. While the former focuses on regulation change, the latter combines the niche strategies into one path that companies can follow in their endeavour towards MASS adoption and diffusion. Thus, answering the research question: "*How can MASS reach diffusion within the maritime industry?*".

From the academic perspective, this research contributes by validating the BBF and adapting it to the maritime industry context. It also enhances the BBF by adding the importance of each Building Block in the MASS TIS, allowing prioritization in the strategies used to overcome them. It adds to the literature by introducing pathways to diffusion, combining the niche strategies to overcome distinct barriers into one single path, providing a systematic solution to separate barriers to MASS diffusion. On the managerial side, this research contributes by offering scientific support for companies to aid their decision-making process regarding the further steps towards MASS implementation.

This report suggests follow-up similar studies with the addition of interviewees from different countries to verify its external validity and the use of the modified BBF to technologies in other industrial environments. Finally, this research discusses other points that require further research, such as the social and economic impact of MASS in the global economy, the influence of 3D printing in MASS and the maritime industry, as well as the necessary changes in the maritime academies.

Acknowledgements

There was no single day I worked on this thesis without being confronted with the absence of a friend, an amazing friend who left this life too soon. He reminded me of all deadlines, worked with me in every project and with whom I brainstormed all my crazy ideas was abruptly gone. He was gone before we could celebrate this achievement together, but he knows this achievement is not mine, it's ours.

Luckily, I found a lot of great people along the way that helped complete this work on and here is my

SPECIAL THANK YOU!

It all started with the support of Roland, my first supervisor, who always found time to answer my questions, and patience to advise me on how to move on. I am incredibly grateful. And then it came Mark, my second supervisor, who participated in more meetings than he was supposed to and gave me extremely valuable, detailed, and direct feedback. He knows I hated him for his words, just to understand his point hours later transform the hate into gratitude.

This research would not have been possible without all interviewees. People who took time to help a student without anything in return, finding time in their busy agendas to answer my questions with all patience. I was very lucky to meet them along the way, to have the chance to see autonomous vessels from their perspective and build a system overview. I hope this result is somehow useful to their journey because they were all vital to the completion of this thesis.

Since life is much more than technical content, it is impossible not to recognise the incredible background support of my family and friends. My lovely husband, who was willing to learn all innovation concepts and discuss autonomous shipping over the dinner table every day. My parents and sister, who believed in me even when I did not believe myself. My family in law, who took care I kept eating vegetables when I was too busy to cook properly. Finally, my friends, who close by or miles away, forced me to have a night off every Wednesday, offered to read the report, and encouraged me to move on. I am extremely grateful for having you in my life.

I would not have finished this work without your crucial support, this achievement is, without a doubt a team effort. You were the giants whose shoulders I was lucky to stand upon. Thank you!

Dedicated to the memory of my dear friend Shashank.

This achievement feels incomplete without you.

Contents

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1. Introduction

This chapter initially presents the background of this research and the research objective, in which the main research question is introduced. The literature review that comes after is divided into theoretical and Maritime Autonomous Surface Ships (MASS) specific, respectively sections 1.4 Theoretical Background and 1.5 MASS Literature Review. Section 1.6 Literature Review Conclusion concludes the literature review and is followed by sections 1.7 Research Problem, 1.8 Research Contribution, 1.9 Research Question & Sub questions, and finally 1.10 Structure of the Report.

1.1 Background

We live in a world where machines performing a task that was previously operated by humans is no longer a surprise. A quick look in any search website brings commercial offers from cooking robots (Moley, 2020) to robot companions (The Medical Futurist, 2018). Transportation does not stay behind in the autonomous trend. Autonomous cars are so popular that some newspapers, such as The Guardian, have a section dedicated to self-driving cars news (2021). Unmanned aircraft are no different, despite not being so popular in the mainstream news, Boeing ensures there is “a full range of unmanned aerial systems… for a range of customers and missions worldwide” (n.d.).

Despite the reduced general media coverage about this technological advancement, the concept of Maritime Autonomous Surface Ships (MASS) is also a hot topic in the maritime industry. The idea of autonomous ships has been around since 1898 (Wróbel, Montewka, & Kujala, 2017). Only much later, Rødseth (2017) defined “autonomous” as “the ability of a system to independently control its actions to reach a specific goal”. Rødseth (2017) explained that, for merchant marine vessels, the goal is to transport the cargo from one port to another in a timely and efficient manner. Combining this long-term ambition with the latest technology advancements, sparked the interest in researching unmanned merchant vessels (Wróbel, Montewka, & Kujala, 2017).

1.2 Research Objective

Wróbel, Montewka, & Kujala (2017) claim that navigational accidents can be reduced in unmanned vessels if compared to conventional ones. This would also decrease environmental pollution caused by these accidents, which rarely occur, but despite their infrequency, cause invaluable environmental damage (Rødseth J. Ø., 2017). In addition to safety increase, reduction of fuel costs, as well as more efficient use of ship space, encourage the development of this technology (Sencila & Anatoli, 2019).

The latter brings the economical aspect of this technology, which is connected to the global financial impact of the maritime industry.

Maritime vessels carry 90% of the international cargo transported worldwide, making ship transport strategic for many nations (Rødseth J. Ø., 2017). Not surprisingly, this sector depends on the global economy, showing a positive correlation to GDP (Gross Domestic Product), industrial production and merchandise trade (Benamara, Hoffmann, & Youssef, 2019). Because of the current surplus of shipping capacity and the slow growth of the world's economy, ships freight rates have been low since 2016. The trade war between China and the USA, as well as Brexit, may decrease shipping demand even further. In this scenario, shipping global players are open to innovative solutions (Munim, 2019).

The International Maritime Organization (IMO) regulates minimum safety manning, appropriate certification standards, pollution prevention, collision prevention and Port state control (IMO, n.d.). These international conventions rule how ships are currently operated, as well as how they should be built to be certified for operation, a rule that is enforced by classification societies (Perunovic & Vidic – Perunovic, 2011).

Lloyd's Register (2016) and Bureau Veritas (2019), industry leaders classification societies, have already defined autonomy levels for the design and operations of autonomous ships, and IMO has developed guidelines for trials of autonomous ships (IMO, 2019). However, many other barriers hamper further MASS development, such as equipment reliability, the safety of the cargo (Felski & Zwolak, 2020), cybersecurity threats (Yoon, Choi, & Seo, 2018) and possible increase of non-navigational accidents, such as fires and structural problems (Wróbel, Montewka, & Kujala, 2017).

Everett M. Rogers, the father of innovation research simply defines diffusion as "the process by which an innovation is communicated through certain channels over time among members of a social system" (Rogers, 1985, p. 5). Later in the same book, Rogers classifies 5 adopter categories related to the innovativeness of the individuals, focusing on the adoption process of a given technology, once it is readily available in the market.

From another point of view, Ortt presents a pattern of diffusion innovation model that analyses a technology before its diffusion. Instead of focusing on the adoption of a specific technology, Ortt defines three milestones: (1) invention; (2) first market introduction; and (3) diffusion to analyse the diffusion pattern of the technology. Ortt does not consider the adoption as a unit of study, but the pattern followed by the technology before its diffusion starts. The author defines the presence of three elements that characterise diffusion: (1) a standard product that can be produced many times;

(2) an industrial production of the standard product; and (3) diffusion of the product. The last element follows the above-mentioned Rogers model of diffusion.

Both definitions from Ortt (2010) and Rogers (1985) make apparent that autonomous ship technology is not yet in its diffusion phase. However, the current literature does not clarify in which pre-diffusion phase it is. The pattern of diffusion innovation model suggests that actors and factors present before the diffusion of the technology can shape its development and contribute to a longer or shorter period until market introduction (Ortt J. R., 2010). This model indicates that the analysis of the pre diffusion state of the technology helps to identify factors and actors that increase (or reduce) the time elapsed between the invention and the market introduction of the technology.

Following up on the pattern of diffusion innovation model, Ortt & Kamp (2021) developed the A Technological Innovation System Framework to Formulate Niche Introduction Strategies Prior to Large-scale Diffusion. In this framework, the authors propose an analysis of several aspects that must be present for the diffusion of breakthrough technology, these aspects were nicknamed Building Blocks. The building blocks focus on the technology itself as well as the environment in which it is being developed. The framework follows the idea of Bergk et al. (2008), in which a Technological Innovation System (TIS) is composed of actors, networks and institutions, which contribute to the development, diffusion and utilization of new technological products.

A further step in academic studies is to develop a pathway to achieve MASS diffusion. This is achieved by a combination of models and frameworks. First, a MASS analysis using the TIS perspective is achieved by combining a description of the external and internal technological environment, and the use of the Technological Innovation System Framework to Formulate Niche Introduction Strategies Prior to Large-scale Diffusion (Ortt & Kamp, 2021). Both are detailed in sections 1.4.3 Technological Innovation System (TIS)and 1.4.4 Building Blocks Framework[2] respectively. This approach builds a picture of the TIS in which MASS is being developed.

A pathway to MASS diffusion depends on its diffusion phase, therefore The pattern of diffusion innovation model (Ortt J. R., 2010), shown in section 1.4.2 Pre-diffusion Model[1], is used to determine the pre-diffusion stage in which MAS. Once the pre-diffusion phase is known and the actors and factors affecting MASS TIS are determined, Technology introduction strategies, highlighted in section 1.4.5 Technology Introduction Strategies, are used to develop a pathway to overcome hampering factors, granting MASS full diffusion within the maritime industry. Precisely focusing on the question:

"How can MASS reach diffusion within the maritime industry?"

1.3 Literature Review Introduction

This literature review is divided into 2 sections: the theoretical background and MASS specific literature. Section 1.4 Theoretical Background presents the perspective about diffusion and pre-diffusion of emerging technologies, including the analysis of a Technological Innovation system, the identification of actors and factors that affect the technological diffusion and finally market strategies designed to introduce new technology products to the market.

The second section is the literature focused on exploring barriers and encouraging factors to MASS adoption. Where barriers are factors impeding or delaying the innovation and encouraging factors act promoting the adoption of a newly developed technology (Hueske & Guenther, 2015). The unit of analysis of this study is the diffusion of the technology, nonetheless, the diffusion can only be achieved through mass adoption (Rogers, 1985). Therefore, within this report, barriers to adoption will be treated as barriers to diffusion unless otherwise specified because there is no diffusion without technology adoption.

This MASS specific literature review covers the non-technical literature about MASS published until January 2021. Here technical literature is considered to contain articles and publications about the mathematical models, development of algorithms, sensors and the equipment used to make MASS operational. The MASS specific literature review covers presents are an overview of MASS, explaining the technology potential, a discussion about its safety, cybersecurity, crew reduction & economic considerations, as well as regulations according to the available literature.

1.4 Theoretical Background

1.4.1 Technological Diffusion

“Innovate or die” (Jagersma, 2003) makes it clear that innovation is central to growth in every industry, worldwide. The author sets a sense of urgency, presenting innovation as a path to success that should be widespread. Jagersma was neither the first nor will be the last studying innovation. In fact, innovation itself has always existed, but the idea of innovation as an invention that will be commercialized started in the 1950s, later being defined as the process between invention and diffusion (Godin, 2008).

Rogers (1985) considers diffusion a sort of social change that happens when new ideas are invented, diffused, and adopted, which, in his opinion, leads to social change. In his words “an innovation is communicated through certain channels over time among members of a social system” (Rogers, 1985, p. 10). Rogers developed a model to explain the diffusion of an innovative product by dividing the general population into 5 groups according to their purchase behaviour of innovative products. The cumulative frequency of these individuals adopting a new technology over time is represented by the S curve of innovation adoption, shown in Figure 1. This curve is currently used as a predictive tool in businesses to forecast when a technological product will reach its limit, signalling the time to move to a more radical technology (Schilling, 2017).

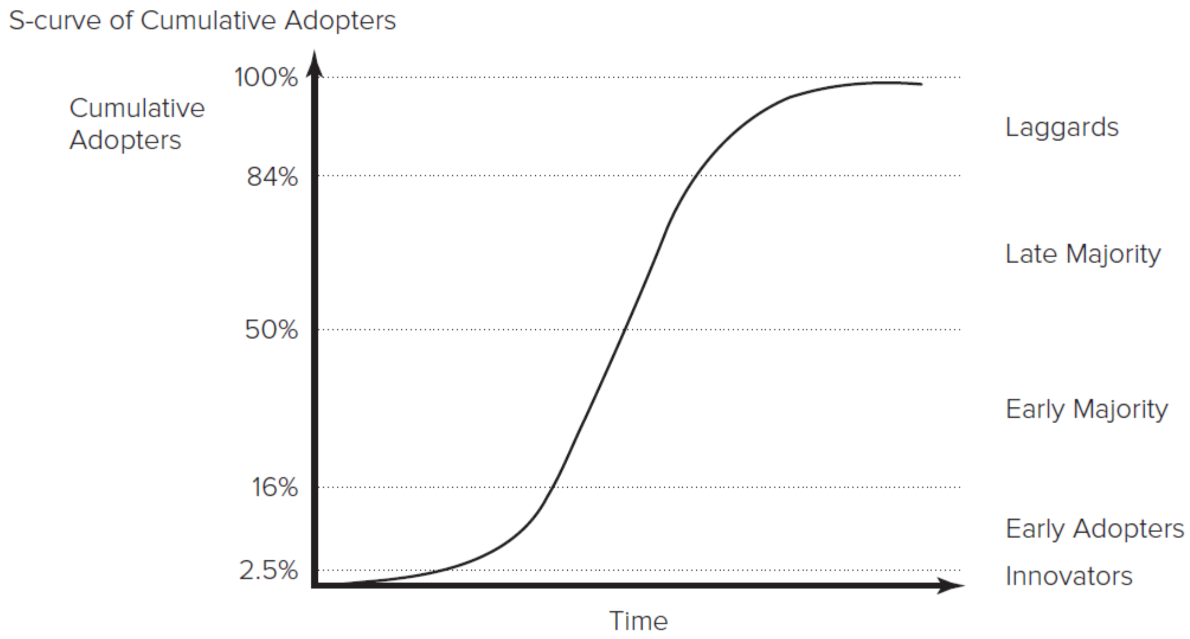

Figure 1- Technology Diffusion S-Curve with Adopter Categories (Schilling, 2017, p. 58)

To understand diffusion, it is important to comprehend the innovative process, the different types of innovation and how they can reach diffusion. Schilling (2017) presents four dimensions most commonly used to categorise innovations, depicted in Figrue 2. In her view, innovation can be embodied in the output of an organisation, in the form of a product, as well as in the process a company uses to make its products. Innovation can be characterized based on the effect it has on the current knowledge of a company and the performance of its product. In this context, if the innovation builds upon existing knowledge or performance, it is competence enhancing. On the other hand, if it replaces the product offered or hinders the existing knowledge obsolete, it is competence destroying.

While architectural innovation changes the way components interact with each other, modifying its overall design, component innovation is related to the adjustment of the components within the system, maintaining the overall design and functionality inherently the same. Finally, the continuum between radical and incremental innovation represents the degree of newness or differentness which an innovation represents when compared to the status quo. Incremental represents a small adjustment to prior solutions and products, while radical innovation stands for a fundamentally different solution (Schilling, 2017).

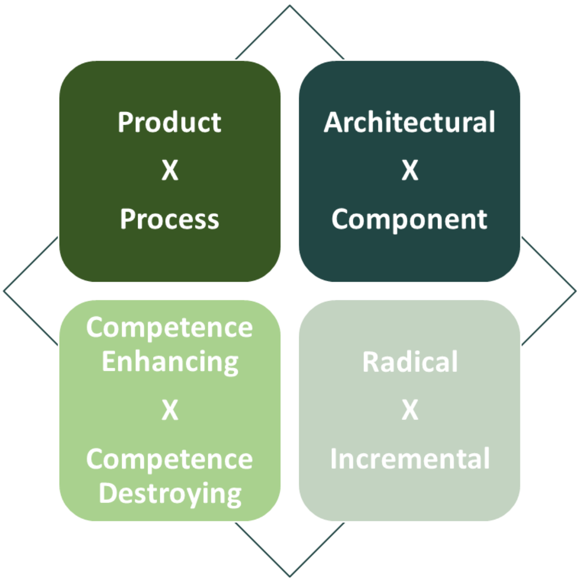

Figure 2- Dimensions of Innovation

These dimensions are not mutually exclusive and depend on the perspective it is being analysed. On the one hand, an original equipment manufacturer might categorise a new fuel filter as a radical architectural competence destroying innovation, when the new product makes the previous version obsolete, for example. On the other hand, a car manufacturer can consider the same filter an incremental component competence enhancing innovation for its existing models (Schilling, 2017).

Radical innovation is considered challenging, a type of innovation that requires special resources and reflects substantial risk if compared to incremental innovation (Kahn, 2018). Related to radical innovation, disruptive innovation is one of the most widely used terms in the innovation management literature. Coined by Clayton Christensen, the term disruptive innovation originally means a radically new product that initially underperforms in the mainstream customers perspective but attracts alternative customers with different needs. Over time, the disruptive innovation improves its performance and becomes appealing to both mainstream and alternative customers, defeating the status quo solution (Schmidt & Druehl, 2008).

Aligned with the concept of disruptive innovations, but focusing only on technological innovations, Ortt et al. (2007) describe breakthrough technologies as a significant technological advancement that drastically alters the price/performance ratio of a specific product. In another scenario, breakthrough technologies may also lend themselves to a completely new kind of application, changing the perspective of the end-users regarding that technology.

While commercializing breakthrough technologies can lead to high rewards and potential competitive advantages, it is also very risky. The risk of innovating exists because diffusion is rather the end of the innovation process that includes many phases (Godin, 2008), many technologies take decades to reach diffusion, while some never become fully diffused (Ortt J. R., 2010).

1.4.2 Pre-diffusion Model[1]

[1] The content from pages 7 – 10 is based on the Article: Ortt, J. R. (2010). Understanding the pre-diffusion phases. Gaining momentum managing the diffusion of innovations, 47-80.

The Pre-diffusion model (PDM) (Ortt J. R., 2010) focuses on the phases before large-scale diffusion of breakthrough technology, before the product achieves the S-curve stage of its development, therefore a different time frame than the Diffusion Model developed by Rogers depicted in Figure 1. The PDM add the demand standpoint to the customer's perspective explained in Roger's diffusion model (Rogers, 1985), considering factors that could hamper diffusion even before there is a demand for the product, such as incapability of large-scale production.

The PDM aims at breakthrough technologies and it works on the assumption that not every product follows the S diffusion curve right from its invention. Technological innovation often continues in the period between its invention and the large-scale diffusion, a period in which the product undergoes adaptations such as improvements, or changes to ensure its economic viability.

Pre-diffusion Milestones

The PDM categorises the technology evolutionary development into three pre-diffusion milestones to evaluate the diffusion status of a high-tech product:

1 **Invention:** The first time the technical principle (of application in a new functionality) is demonstrated and mastered.

2 **Introduction:** The date at which the product is available for sale or distribution (when the product is not meant to be directly sold but offered as a service).

3 **Large scale production and diffusion:** The presence of these three elements listed below separates pre-diffusion phases from the standard diffusion process. After this milestone, starts the large-scale diffusion, represented by Figure 1.

   3.1 A standard product that can be manufactured many times, or standard modules based on the same standard platform that can be combined in different ways to achieve the same technological result.

   3.2 Large-scale production with dedicated production lines

   3.3 Diffusion of the product.

Ortt (2010, p. 12) divides the pre-diffusion period, defined by the three abovementioned into two different phases:

1 **Innovation phase:** From invention until initial market introduction.
2 **Adaptation phase:** From the initial market introduction to industrial production and large-scale diffusion.

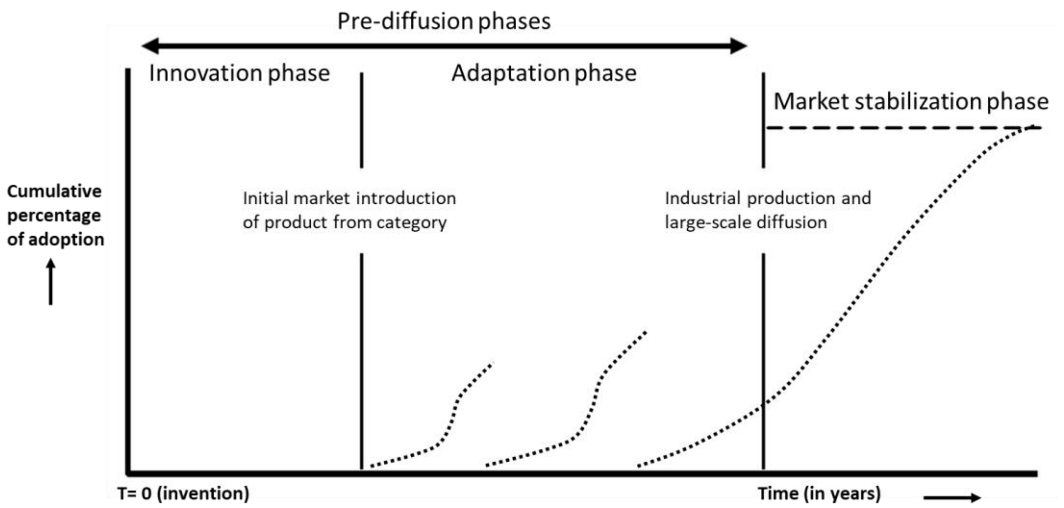

Figure 3 - The pattern of development and diffusion of high-tech product categories *(Ortt J. R., 2010)*

The PDM shows that before achieving large-scale diffusion, technologies go through the innovation and adaptation phases, a process that is less predictable than the S-curve pattern of diffusion. The duration of these phases varies across industries, while some have relatively short pre-diffusion phases, such as chemicals and metals, others have much longer periods. The PDM categorises three categories of factors that influence the length of the pre-diffusion phases: the main organizations responsible for the development, supply and use of the new high-tech product; the technological system required to use the new high-tech product; and the market environment.

The main organization(s)
Fit with the mission and other criteria of companies to evaluate the importance of the product for the company
Customer need and other customer-related criteria are needed to evaluate the product
Cheapness for producer/supplier (overview of costs/benefits)
Cheapness for the customer (overview of costs/benefits)
Resources of the main actor (to develop, produce and supply)
Resources of the customer (ability to adopt and use)
Expertise (to develop, produce and supply innovation)
Expertise (to use innovation)

Adoption strategy
Market (supply) strategy
Number of potential customers (market and potential)
Number of suppliers for product and technological system; number and resources of suppliers of alternative products/technological systems
Network effects on the customers' or suppliers' side
Cooperation/competition among different actors
The technological system
Relative performance compared to alternative technology
Competition with other new/old technologies
Required and available complementary products
Reliability, certainty, and risk of technology
Complexity and network requirements of technology
Availability of knowledge components (newness)
Difficulty in controlling production
Type of technology (basic, general-purpose and/or competence destroying technology)
Visibility of benefits
Unknown applications of technology (newness)
Ease of translation from invention to innovation
Compatibility with similar systems in other regions or with previous systems
The market environment
Regulatory environment
Availability of rules and standards
General public attitude
Accidental changes in the macro environment
Accidents during development/ exploitation

Table 1 - Categories of factors found to affect the pre-diffusion phases (Ortt J. R., 2010, p. 43)

The factors mentioned in Table 1 influence the length of the pre-diffusion period in different ways. While some influence it directly, such as the need for infrastructure for the use of a giver high-tech product, others are less straightforward. Often there is a combination of factors that influence the pre-diffusion phase simultaneously, such as the fit of the new technology to the mission of the organization and the allocation of resources to its development. Contextual and time-dependent factors also have an important influence in the pre-diffusion phases.

Market research for breakthrough technological products adds complexity to the pre-diffusion period since most market research standard tools work on the assumption of identified customer segments, who will be able to evaluate the impact of the product in their lives. These assumptions, however, rarely apply to the customers of new technology. At the time a high-tech product is invented there is little to no certainty about its pre-diffusion, despite the profound consequences pre-diffusion phases have for companies trying to commercialize high-tech products.

The above-mentioned consequences mainly occur because the innovative product requires investments and does not deliver financial income during pre-diffusion phases. This lack of financial returns comes with uncertainty about the type of pattern that will unfold for a given new high-tech product, which will, in turn, affect the timeline of the expected profit of the innovative product. That is the reason many companies are not able to reach the large-scale diffusion of their products.

1.4.3 Technological Innovation System (TIS)

Given the financial risk involved in bringing innovative products to the market, many researchers have focused on innovation management. Van der Duin, Ortt & Aarts (2014) explain that Innovation management evolved in its pursuit of improvement of innovative product success rate, starting from linear innovation processes, later going to iterative and arriving at a network approach. The authors suggest that there is no “one size fits all” solution for innovation management, indicating a contextual approach instead.

A contextual approach entails that the development of innovative technology or a new application to already known technology does not happen on its own, but it is part of a system (van der Duin, Ortt, & Aarts, 2014). Bergek et al (2008) define a system as a group of components, serving a common goal, in the case of a Technological Innovation System (TIS), the components are the actors, networks and institutions contributing to the development, diffusion and utilization of new technologies and processes. The components of the TIS are often also called actors and factors of the TIS.

Bergek et al (2008) explain that despite being part of the same system, TIS actors often do not share common goals, and even when they do, their actions are mostly uncoordinated. The authors also explain that an innovation system is mainly a tool to understand the system dynamics, implying that the system itself might not be fully visible, but arise from weak interactions between its components.

Therefore, Bergek et al (2008) suggest that to better understand technological development, it is necessary to have a broader focus than the technology itself, including the internal developments of the industry in which the technological innovation is being developed and its external environment. This broader analysis allows a better understanding of the innovation in its context and enables further analysis of possible barriers that impede the diffusion of innovative technologies.

In a TIS, barriers are factors that impede or delay innovation, also commonly termed hampering factors. The capacity to recognize these barriers requires awareness of the difficulties encountered in the innovation process and it is paramount to overcome these barriers (Hueske & Guenther, 2015). Ortt and Kamp (2021) used the perspective of TIS as a tool to analyse the context of breakthrough technology with the idea that barriers need to be identified, understood, and solved into the Building Blocks Framework (BBF).

Ortt & Dees (2018) focus on 3 main perspectives to define a breakthrough technology in a TIS, namely: Functionality, operational principles, and components. Once the technology is fully defined, the authors evaluate the current applications using the Building Blocks Framework, which is defined in section 1.4.4 Building Blocks Framework[2], to understand the context in which technology is being developed and evaluate which factors encourage, hamper, or have no influence on the technology development.

1.4.4 Building Blocks Framework[2]

[2] The content from pages 11 – 15 is based on the Article: Ortt R. and Kamp L. *A Technological Innovation System Framework to Formulate Niche Introduction Strategies Prior to Large-scale Diffusion.* 2021

The Building Blocks Framework (BBF) was developed by Ortt and Kamp (2021) to identify actors and factors that are important for the large-scale diffusion of radically new technological innovations. This framework builds on the perspective presented by PDM. The framework further specifies the identified categories that influence the length of the pre-diffusion phase presented in Table 1 - Categories of factors found to affect the pre-diffusion phases and presents general building blocks that can act as a barrier if absent, incomplete, or incompatible with the TIS environment.

The BBF takes into account the system perspective, explained in section 1.4.3 Technological Innovation System (TIS), and includes the market and the company perspectives, considering also actors that are involved in influencing the interplay of supply and demand sides. This framework identified seven building blocks, which are actors and factors that need to be fully present to achieve large scale diffusion of breakthrough technology. Hence, if one of the blocks is missing, incomplete, or incompatible with the others, that will form a barrier to the technological innovation large-scale diffusion process.

1.3.3.1 Building Blocks

TIS Building Blocks

Product Performance and Quality	The newly developed technological product has sufficiently good quality and performance or is expected to have it shortly when compared to competing products. If the new technology suffers from low quality and is unable to meet customer’s needs and requirements large scale diffusion will be hampered.
Product Price	The price of a product involves not only its monetary costs but also non-financial costs such as time, effort to implement the new product, switching costs, and costs to find new suppliers. For large-scale diffusion, the price should be reasonable when compared to other competitive alternatives of the same technology.
Production System	A production system that can deliver large quantities of high-quality products is paramount to the large-scale diffusion of technological innovation. Not only creating a production system but fine-tuning it to profit from the learning effect costs time and money, which can delay the diffusion process.
Complementary Products and Services	Complementary products and services support production, distribution, adoption and finally the disposal, if necessary, of the innovative technological product. Together, the network of complementary products and services can induce other innovations and motivate companies to align their strategy, which will ensure large-scale diffusion. The lack of these products and services forms a barrier that blocks the diffusion.
Network Formation and Coordination	A supply chain network with suppliers of parts, distributors, complementary services, and other actors is important for the diffusion of an innovative product. The lack of alignment in this network can impede the large-scale diffusion of the technology.
Customers	The customers are extremely important in the TIS and the diffusion of the innovative technology, without consumers, there is no diffusion. Customers must be able to afford the product, understand enough the product’s capabilities to have the correct understanding of its risks and benefits, as well as use it. The development of technological innovation without the perspective of the future customer often results in issues that hamper diffusion, such as lack of integration with the customer’s routine of use, alignment to other technologies already in use. Some technologies have to be adjusted later to fit customer’s wishes.

Innovation-Specific Institutions.	To form a TIS network, innovation-specific institutions must be present. These institutions refer to regulations, laws, standards, and government policies, which can either block or encourage the formation of the TIS. Factors such as stability of the political and legal systems, quality norms, and property rights produce trust in the system, which in turn, increases investments and facilitate the TIS formation.

Table 2- Building Blocks Description (Ortt & Kamp, 2021)

Only the analysis of the seven building blocks is not enough to conclude which strategy suits the market entry of the innovative product because the analysis does not present an underlying cause for the barrier. Often the nature of the barrier does not explain why it exists, e.g., the fact that the building block “customer” is incomplete does not explain why customers are not enthusiastic about the innovation offered. Knowing that the customers are a barrier is a starting point but to develop a strategy, however, it is necessary to understand what influences the customers and in their decision of not being interested in the innovation. The same logic can be extended to all seven building blocks mentioned in the BBF.

Therefore, to complete the framework, Ortt & Kamp (2021) introduced seven influencing factors, which indicate the causes of barriers to achieve large-scale diffusion of radically new technological innovations. The analysis of the building blocks and their influencing factors provides a better TIS outline and allows a company to choose the best strategy to address the underlying cause of the building block absence, incompleteness, or incompatibility.

1.3.3.2 Influencing Factors

Technology Innovation System Influencing Factors

Knowledge and Awareness of Technology	This aspect refers to both fundamental and applied knowledge. They comprise knowledge about the product itself, its production system, and complementary products, as well as the knowledge about its application, which is necessary to develop, produce, maintain, and use the product. Actors in the TIS need to be aware of both types of knowledge, which can be developed through research and practical experimentation. The process of learning about technological innovation, mainly through education, is vital to increase both types of knowledge.
Knowledge and Awareness of	This influencing condition relates to the use and applications of innovative products, as well as the market structure and its relevant actors. Lack of application knowledge can affect customers as well as suppliers. Suppliers

Application and Market	without application knowledge are not able to target the correct customer segment, and customers without knowledge of the purpose, how to use or buy an innovative product will be a barrier to product diffusion. Market analysis, experimentation, and learning by doing are ways of developing this type of knowledge.
Natural, Human and Financial Resources	All three types of resources, natural, human, and financial are required for the production system of the innovation itself as well as the complementary products and services. The lack of raw material, people with the necessary competencies or capital to invest in technological innovation can hamper technology diffusion. The lack of financial capital specifically blocks the development of radically new products and their future market formation.
Competition	The presence of competition influences the market formation, especially when there are alternative competing technologies requiring different components, production systems and complementary products. Such a situation leads to uncertainty, which hampers market formation, an important building block for large-scale diffusion. The competition also influences the relative price and performance, shaping the investment in production and complementary products and finally influencing customer adoption.
Macroeconomic and Strategic Aspects	The macro-economic situation can largely influence the conditions for the TIS formation. While economic growth facilitates the formation of TIS with funds for incubators, for example. An economic recession can hamper the large-scale diffusion of a breakthrough innovation given the reduction of these incentives to innovation. The strategies and country policies are often affected by macro-economic conditions, such as the market structure, making both macro-economic and strategic aspects not only dependent on each other but also of large influence in the TIS building blocks.
Socio-Cultural Aspects	The socio-cultural aspects are the norms and values held by the potential customers and stakeholders of innovative technologies. These norms are not necessarily laws, policies, or regulations, but informal common norms that impact the behaviour of TIS actors. These rules change with time, and they can influence technology adoption in both ways, encouraging or blocking the technology large-scale adoption.
Accidents and Events	Events such as wars, or natural disasters, together with national or international accidents generate a great impact on the formation of TIS-es. Some of these events stimulate the formation of TIS for radically new technologies because

	they generate new needs, which have to be fulfilled with innovative technologies.

Table 3- TIS Influencing Factors (Ortt & Kamp, 2021)

The combination of the TIS building blocks status, and the influencing factors for those incomplete or incompatible building blocks, allows a company to develop a niche strategy focused on resolving the root cause to introduce the product to the market in a successful manner. This approach allows a company to initially introduce the product to a small group of customers with specific needs, hereinafter niche markets until the building blocks are completed and aligned. This approach ensures the company can start profiting from the product before it is ready for the mainstream customers and gives the chance to improve products based on users' experiences. The picture below represents the layers of the TIS building blocks and their relationship with the influencing factors

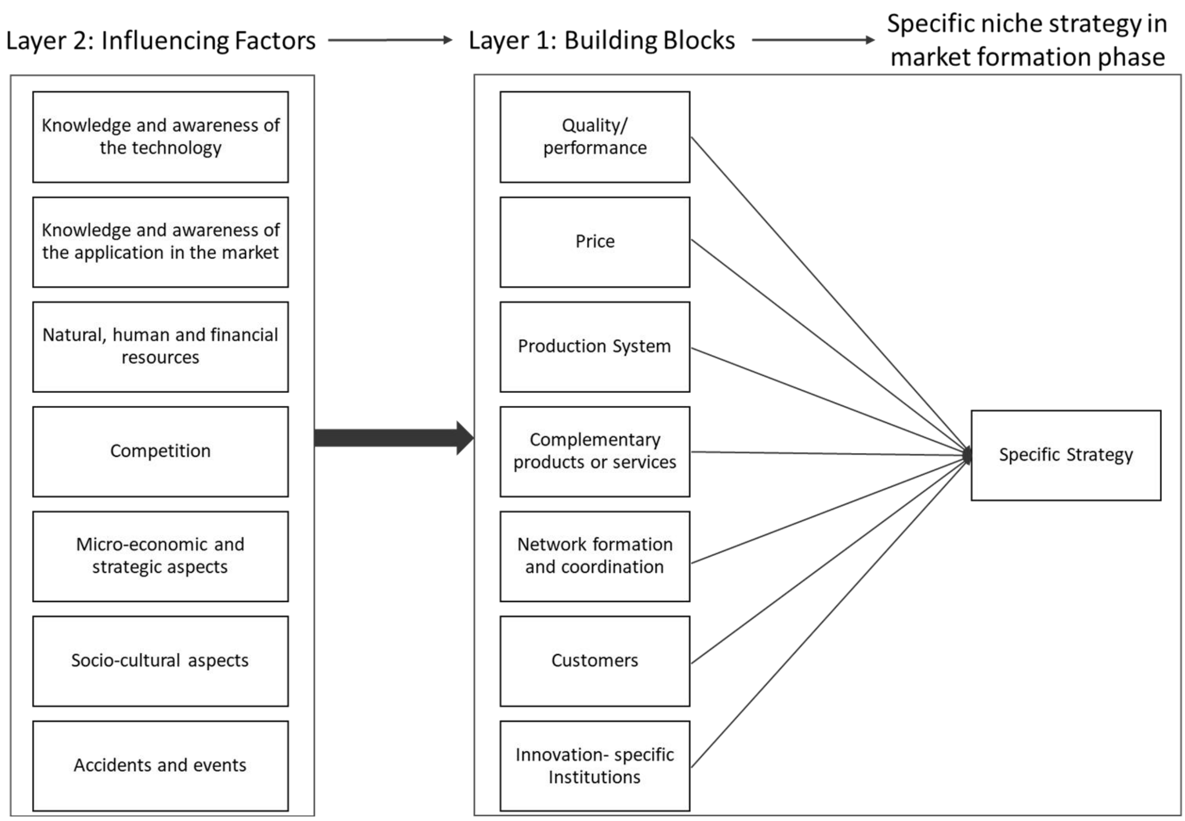

Figure 4- Technological Innovation System Framework to Formulate Niche Introduction Strategies Prior to Large-scale Diffusion (Ortt & Kamp, 2021)

1.4.5 Technology Introduction Strategies

For any company, defining a strategy requires a broad analysis of the environment in which the company operates, which often include the use of strategic management tools such as Porter's 5 forces analysis, Porter's value chain, combined with stakeholders' analysis. Combined, these analyses help a company to determine their strategic intent, or its long-term goal. The strategy to introduce a product to the market needs to be aligned with the strategic intent of the company to ensure the company will achieve its desired results (Schilling, 2017).

Schilling (2017) explains that there are mainly 2 pathways to introduce an innovation to the market. A company can go solo, which means opting for secrecy and maintaining all the technological developments in-house to ensure control and maintain the property of the technology. Or it can choose for collaboration, where it can count on the collaboration of a network of companies that collaborate on the same technology. Collaboration, however, is not always simple.

Dasaratha (2019) notes that companies need to find a balance between protecting intellectual property and interacting with other firms, which enhances the knowledge about the technology but also increases competition. The author explains that a dense technological network adds value to all companies taking part in it, increasing profitability and welfare gains. However, network formation is not simply achieved because most companies want to guarantee their intellectual property. To ensure network formation, the author introduces the idea of a public innovator, which has no incentives to be secretive and is willing to interact with all parties. Such a public innovator can be a university or a governmental research institution and can serve as an intermediary, facilitating the network formation and the learning process that benefits all companies participating in the network.

On a more product-oriented approach, Ortt, Langley, & Pals (2013) suggest 10 niche strategies to commercialize high-tech products. These strategies are based on the actors and factors suggested by the Building Blocks Framework (Ortt & Kamp, 2021) presented in section 1.4.4 Building Blocks Framework[2] and detailed in Table 2 and Table 3. Ortt (2012) defines niche markets as relatively small groups of customers with unique wants and demands regarding a product. Within the context of innovative technologies, he considers strategic niches the applications for which there is a niche market before the large-scale diffusion of radically new technology in the mass market.

Gerlagh et al. (2004) state that a niche market can help the development of new technologies advancing diffusion and allowing them to mature while in use. The authors also add that most innovations are not immediately financially attractive, making the niche strategy a possibility to grow in niches where cost-effectiveness is not of primary importance.

Based on the idea of market niches, Ortt, Langley, & Pals propose 10 niche strategies to commercialize new high-tech products. They explain that the choice for a specific niche strategy depends on a combination of factors, related to the presence or absence of the building blocks presented in Table

2- Building Blocks Description as well to the factor influencing the building block itself. Table 4 presents the 10 niche strategies and their brief explanation.

Niche Strategies	Definition
Demo Experiment and Develop Niche	Demonstrate the product in a controlled environment to enhance public knowledge about it and use the experiments to further develop the product quality. Relevant when knowledge of the technology is lacking.
Top Niche	Offer a limited number of products to the specific top-end of the market that is not price oriented until production capacity is feasible. Appropriate to when knowledge of the technology is lacking and it affects its price.
Subsidized Niche	Subsidize the product for a particular segment if its use is considered socially important, but it is too expensive for the target customer. Applicable to when the product is too expensive to the market, or when resources are scarce.
Redesign Niche	Introduce a simpler version of the product that can be produced with limited resources and sold at a lower price to explore the market. Appropriate when the product is too expensive to the market, when resources are scarce, or to fit socio-cultural aspects of suppliers and customers.
Dedicated System Niche	Offer the option of using the high-tech product independently from complementary products. Suitable when lack of knowledge about the technology affects the availability of complementary services.
Hybridization or Adaptor Niche	Combine the new product with the old one, allowing the use of all complementary products and services, or make the new product compatible with the existing complementary services. Applicable when resources are lacking, affecting the availability of complementary products.
Educate Niche	Educate customers and suppliers about the high-tech product to increase knowledge and awareness of the product capabilities. Useful when knowledge of the technology is lacking, affecting availability of suppliers and customers.
Geographic Niche	Introduce the high-tech product where laws and rules are less strict, or where customers, suppliers and resources are already available. Suitable when socio-cultural or macro-economic aspects affect the customers, and when institutional aspects pose a barrier to technology adoption.

Lead User Niche	Partner with lead users and innovators to co-develop products that innovators are willing to experiment with. Applicable when knowledge of the application is lacking, affecting a clear view of customer's applications.
Explore Multiple Markets Niche	Introduce the high-tech product in different customer applications to stimulate the explorative use in new functions. Relevant when knowledge of the application is missing, reducing the visibility of product application, usage pattern and benefits.

Table 4- 10 Niche Strategies (Ortt, Langley, & Pals, 2013)

1.5 MASS Literature Review

1.5.1 MASS Potential

Vagale et al. (2021) state that the MASS market is expected to have a fast growth rate soon. In terms of volume, the MASS market is expected to grow at a rate of 26.7% in the period between 2024 and 2035, generating cumulative revenue of nearly 3.5 billion USD by 2035. The article goes in-depth about mathematical models for MASS path planning and collision avoidance, nonetheless, it starts with a list of potential advantages and challenges affecting the technology, presented in Table 5- Potential Advantages of MASS Vagale et al. and Table 6- Potential Challenges of MASS Vagale et al. .

Potential Advantages of MASS
Less (or absent) human control, reducing human errors
Longer duration performance, allowing more hazardous missions
Improved reliability compared to remotely controlled unmanned surface vehicles (USV)
Enhanced controllability, flexibility and deployability
Suitable for so-called dull, dirty, dangerous, and harsh missions
Reduced personnel costs and improved personnel safety
Extended precision and functionality
Reduced risk of piracy and kidnapping of crew members
Increase space for cargo by eliminating crew accommodation
Removed the need for the navigational bridge by placing sensor optimally around the vessel

Table 5- Potential Advantages of MASS Vagale et al. (2021)

Potential Challenges of MASS
Navigation Safety in poor weather conditions
Cybersecurity – hackers might take unauthorized control of the ship
Piracy and hijacking of the cargo
Unclear Regulations about MASS requiring international cooperation
Definition of Liability without captains onboard
Maintenance & reliability of equipment on board
Unreliable connectivity in some areas or due to bad weather

Table 6- Potential Challenges of MASS Vagale et al. (2021)

The advantages presented in Table 5- Potential Advantages of MASS Vagale et al. are what numerous large projects worldwide about autonomous ships seek to achieve. Examples of these projects are the Norwegian companies Yara and Kongsberg development for a fully autonomous short sea ship, and the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN). There are also companies focused solely on the development of Autonomous vessels equipment as an example of Sea Machines (Wright, 2020).

In addition to these, international initiatives such as ONE SEA and Autoship bring together market parties, governments, and knowledge institutions focusing on the developments of autonomous shipping and autonomous sailing (AUTOSHIP, 2020) (DIMECC, 2017). On national levels, The Netherlands developed SMASH, Nederlands Forum Smart Shipping (2021), Denmark developed ShippingLab (2021), and the Korean government formed a consortium with large companies to research and develop autonomous ships (Ha, 2019). All mentioned projects are academic, governmental and industry joint projects focused on autonomous ships development.

1.5.2 Safety

A point that makes MASS interesting is its potential to increase safety at sea. Rødseth argues that in today's shipping industry, humans are still the most important underlying cause of marine accidents, and most of these accidents harm the ship itself or its crew. In the British maritime industry, the number of fatal accidents per 100,000 workers is 21 times higher than the general British workforce (Rødseth J. Ø., 2017). When compared to the construction industry, the safety record of the maritime industry is 5 times worse. Accidents caused by human errors cost priceless lives and 1.6 billion dollars in insurance costs (Wärtsilä, 2021).

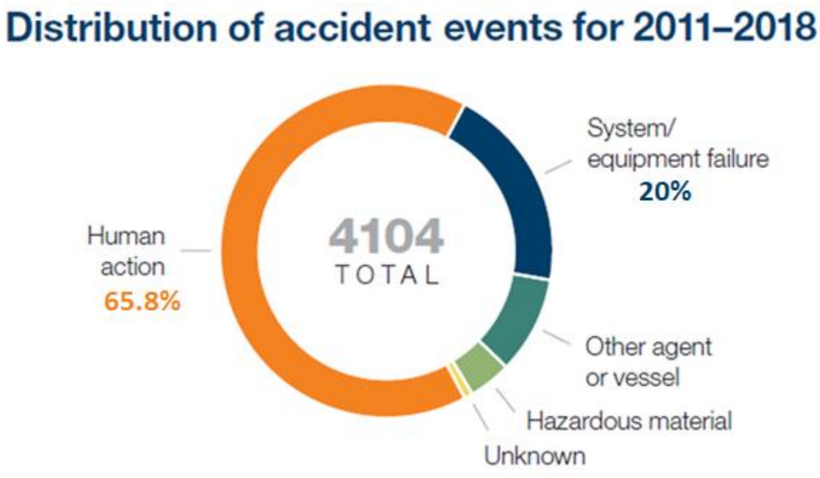

Figure 5- Distribution Maritime Accidents (Wärtsilä, 2021)

The Normal Accidents Theory (NAT) suggests that most accidents are significantly incomprehensible and could not be prevented. The NAT refutes the idea of human error as an underlying cause for most accidents, explaining accidents can be caused by the systems themselves (Perrow, 1999). However, the data from maritime accident analysis between 2011 and 2018 presented in Figure 5 shows that nearly 70% were caused by human error (Wärtsilä, 2021).

Komianos (2018) states that maritime accidents are commonly a result of fatigue caused by a high workload, which is caused by the reduced number of crew members on board. Poor visibility, poor leadership and inclement weather are also common factors behind accidents (Wärtsilä, 2021). Despite agreeing that human error is the cause of many accidents, Komianos (2018) argues that autonomous ships' safety is not as straightforward as it seems. The author proposes a holistic approach including all systems involved, considering not only the ship but systems ashore and the connections between these systems to evaluate if unmanned vessels will be safer.

Wróbel, Montewka, & Kujala (2017) explain that demonstrating an increase in maritime safety is establishing the absence of accidents, which is not simply achieved. It is difficult because there is no documentation about when a seafarer avoided an accident, as it is part of their daily job. No crewmember bothers to report changing course to avoid a collision or fixing a leaking pipe to ensure water tightness. In this perspective the influence of the crew on the number of accidents is unknown.

The association of shipping and inland waterways conducted an interview with seafarers about their view of autonomous ships and they did not agree autonomous ships would become safer. In fact, 85% of the interviewees consider unmanned vessels a threat to safety at sea. The seafarers interviewed argued that simple failures, such as leaking pipes and broken pumps, could escalate to large accidents without the intervention of the crew (Nautilus Federation, 2018).

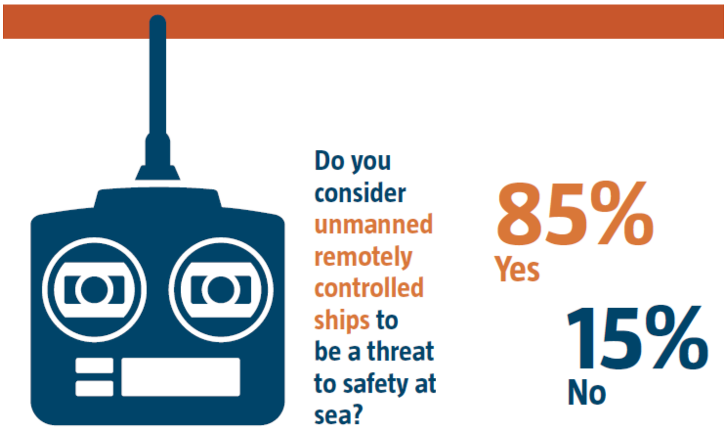

Figure 6- The MASS threat to the safety (Nautilus Federation, 2018)

Specifically aiming to clarify the divided opinions about the safety benefits of unmanned vessels, Wróbel, Montewka, & Kujala analysed 100 maritime accident reports. They concluded that particularly navigation-related accidents could be reduced, but that the introduction of autonomous vessels would be challenging from a safety point of view. The number of human lives lost at sea could be reduced with autonomous vessels, but the absence of the crew could result in other accidents that jeopardize the ship, the cargo and often the environment (Wróbel, Montewka, & Kujala, 2017).

Ventikos, Chmurski, & Louzis (2020) implemented a System theoretic Process Analysis (STPA) for levels of hazards compared to the level of autonomy achieved by the vessel. This analysis is based on the idea that accidents can be caused by interactions between components even if none of the components fails, which is similar to Perrow's Normal Accidents view (1999). In Ventikos, Chmurski, & Louzis view, each autonomy level can generate different system interactions, which could cause distinct problems. Their study shows that increasing autonomy levels, also increase the possibility of applying mitigation measures attempting to eliminate hazards and losses.

However, the same study shows there were no mitigation levels that could reduce the damage after a failure occurred in all autonomy levels. The authors then conclude that the function of the crew on board is double-sided, sometimes acting as the source of error, and other times as agents that mitigate the consequences of an unavoidable failure. One of the authors' suggestions is to include the human aspect in the autonomous ships, not on board, but as a designer of decisions and safety constraints for the system, giving the crew a different role in the operation of the ship, instead of eliminating it (Ventikos, Chmurski, & Louzis, 2020).

1.5.3 Cyber Security

Currently, conventional vessels have a security officer and a vessel security plan according to guidelines of the International Ship and Port Facility (ISPS) Code. These security measures will have to be transformed into part of the autonomous system to guarantee the security of the vessel at all times (Wright, 2020). Vagale et al. (2021) mention the reduction of piracy as a potential MASS advantage, but the authors also mention the possibility of hackers taking control of the ships as a challenge.

Kobyliński (2018) agrees that ransom requests for the crew would no longer be used by pirates, he adds that unmanned vessels might not even have possibilities for boarding as the current vessels have. However, Kobyliński considers a new type of piracy in the form of cyberpiracy, in which ships are taken over and redirected to harbours where the cargo can be unloaded. Wright (2020) exemplifies possible scenarios for interfering with the voyage of autonomous vessels, such as spoofing the Global Navigation Satellite System (GNSS) receivers into showing a different location, allowing a hacker onshore to misguide the vessel in another direction. If the hackers work in small increments, taking a vessel off-course might even go unnoticed for crew members on the autonomous vessels.

In 2017 A.P. Moller-Maersk suffered a cyber-attack that shut down 4,000 servers and 45,000 computers costing between 250 and 300 million USD. According to Wright, this example shows the potential for monetary loss in case of a cyberattack in autonomous vessels. The complexity of interconnected computer systems, IoT appliances and smart sensors on MASS and SCC requires robust cybersecurity to avoid possible use of MASS for terrorist attacks (Wright, 2020).

1.5.4 Crew Reduction & Economic Considerations

The potential economic benefit of MASS lays mainly in reducing costs with the crew in case of manned vessels and the use of the accommodation space on board for loading extra cargo. Other potential cost reductions could be achieved with savings in fuel consumption due to optimal speed (Kobyliński, 2018). This assumption does not consider the many other functions performed by the crew aside from navigational duties. Bertram (2016) disagree with this perspective and explains that the costs incurred by installing all MASS equipment might add more costs than what is saved by removing the crew. In other words, considering all tasks performed by the crew, keeping the vessel manned might be cheaper after all.

In addition to the accident mitigation role of the crew mentioned by Ventikos, Chmurski, & Louzis (2020) in section 1.5.2 Safety, Kooij (2021) presents the issues of the crew tasks beyond navigation that are not (yet) simply automated. She divided the tasks performed on board into 10 different clusters and created 1024 scenarios to test the suitability of crew reduction using a Crew Analysis

Algorithm. The main conclusion is that reducing the crew is not a straightforward matter and not always financially beneficial.

In some scenarios, Kooij (2021) explains that it is possible to reduce the crew from 12 to 3 members and fulfil all necessary tasks. However, the smaller crew would deliver a reduction of 50% in crew costs because only highly skilled personnel, thus only better-paid crew members would remain on board. This solution would also require changes in the task hierarchy on board and an increased occupation rate per crew member, e.g., the captain would also perform tasks commonly executed by deckhands while holding his/her overall ship responsibility. This poses a problem as the conservative attitude of the maritime industry is also a barrier to the introduction of new work systems (Bertram, 2016).

1.5.5 Regulations

A different aspect of the leadership on board is discussed by Kim & Mallam (2020) on the perspective of legal responsibility of the captain, showing that the captain's liability becomes unclear for remotely controlled vessels. Beyond the responsibility aspect, the regulation is also a complex matter. The legal framework comprises a multitude of IMO regulations that include Safety of Life at Sea (SOLAS), Global Maritime Distress & Safety System (GMDSS), Collision Regulations (COLREGS), Search and Rescue (SAR) and International Convention on Standards of Training, Certification and Watchkeeping (STCW). All these international guidelines were developed for manned vessels and specifically mention tasks to be performed by the crew members in a wide range of situations (Bertram, 2016).

Rødseth (2017) mentions that countries can adapt their regulations to suit MASS as an initial solution, considering that the inland waters shipping regulations fall under the responsibility of the country. The author continues that the lack of international legislation prohibits autonomous ships from international waters, but he does not consider it to be a major disruption for the technology. Kominianos (2018) does not agree with the idea of international regulation being a minor factor for the adoption of autonomous vessels technology.

Kominianos (2018) explains that the lack of regulation prohibits the classification societies from certificating autonomous vessels. This fact makes it impossible for shipowners to insure their vessels, consequently not allowing them to sail. Lloyd's Register, ahead of the international regulation, was the first classification society to classify six levels of ship automation from AL0, where the ship is fully manned to AL6, fully autonomous and unmanned, with no possibility of human intervention (Lloyd's Register, 2016). Bureau Veritas has also created its autonomy scale from A0, where operations are under human control to A4, where the system invokes functions without informing the human, except in case of emergency (Bureau Veritas, 2019). Many other institutes have created their scales of autonomy, but none of them is yet considered the standard one (Wright, 2020).

Following the idea that integrating new and advancing technologies into the regulatory framework, the IMO strategic 2018-2023 plan involves balancing the benefits of the new technologies against the safety and security concerns, and the environmental impact. The Maritime Safety Committee (MSC) recognized that IMO should take a proactive role in the regulatory scoping of the autonomous ships but besides a testing framework with 4 autonomy levels described for the MASS trials (IMO, 2019), there are no changes in the international maritime regulations related to autonomy.

In a broader point of view, Klein et al (2020) evaluate more than the commercial use of autonomous vessels. The authors discuss the legal perspective of unmanned vessels to military use, oil spill removal and surveys. The regulation of this technology depends on the location, meaning that particular areas might also have specific legal restrictions. The article explains that levels of autonomy tend not to be taken into account when considering the legal aspect of the technology, while from the legal point of view it is important to know to which extent is the vessel's operation supervised by someone to determine the liability of the actors involved.

1.6 Literature Review Conclusion

No publication about autonomous ships was found to study the topic under the innovation management perspective, i.e., addressing the barriers, as well as the encouraging factors to the diffusion of the technology. The lack of such a study makes the knowledge about the technology fragmented in different publications, each one focusing specifically on one aspect of MASS technology development, for example, publications focusing on the legal perspective describe the regulatory environment, disregarding safety, and economic aspects. According to Wee & Banister (2016) compiling available literature that is fragmented in different publications adds value making the research gaps more explicit and helps researchers getting a well-structured overview of the subject.

The literature about MASS focuses mainly on 5 points: safety, cybersecurity, economic and regulatory. Despite their importance to MASS diffusion, these highly mentioned factors in the reviewed literature seem a small portion of all actors and factors influencing the technology diffusion. As mentioned in section 1.4.4 Building Blocks Framework[2], Ortt & Kamp (2021) framework analyses a breakthrough technology considering 14 different aspects that directly or indirectly affect its diffusion.

The large number difference between the MASS aspects found in the literature and the proposed by the framework suggests a gap in the literature since other factors are likely to be present in further research about the barriers hampering the further development of autonomous vessels. Therefore, a gap is clear in the literature related to all the barriers hampering the diffusion of autonomous vessels. Some of them seem to be discussed separately, but a clear overview of the external environment in which the technology is being developed is not yet established.

From the theoretical perspective, based on the definitions of breakthrough technologies defined in section 1.4.1 Technological Diffusion, it became clear that MASS is a breakthrough technology. However, none of the models used to evaluate innovative technologies presented in sections 1.4.3 Technological Innovation System (TIS) until 1.4.5 Technology Introduction Strategies were used to evaluate MASS, denoting another gap in the available literature. Therefore, this research aims to use the reviewed breakthrough innovation models and framework to evaluate MASS, bringing a new perspective to the theoretical aspect, validating current models, as well as adding the innovation management perspective to MASS specific literature.

1.7 Research Problem

Bergek et. al (2008) explain that the actors do not always share the same goals, and the innovation system itself emerges from the interaction of the actors and factors present in each innovation system. Therefore, to understand the diffusion of MASS, it is necessary to understand the TIS affecting its adoption and consequent diffusion. Ortt & Kamp Building Blocks framework (2021) suggests 14 Building Blocks that must be present in a TIS so a breakthrough technology can achieve diffusion. This framework, however, was not yet applied to the maritime industry. The following step in the literature would be to evaluate the suitability of this framework in a different industry.

Ortt and van der Duin (2008) propose a contextual approach to innovation, where companies introducing innovations to the market should consider the relationship among the contextual factors when deciding the strategy and time to launch a new product (technology). In the case of MASS, the only proposed strategies found in the literature aimed to overcome single barriers, such as the use of autonomous ships in inland waters to avoid international regulations (Rødseth J. Ø., 2017), or the role of the maritime crew in the development of safety systems (Ventikos, Chmurski, & Louzis, 2020).

Ortt, Shah and Zegveld (2007) discuss niche strategies that companies can use to commercialize breakthrough technologies. In this context, niches are small groups of customers with specific needs regarding a product, while niche strategies are applications for an innovative product that begins before its large-scale adoption, focusing on fulfilling the needs of these market niches before aiming at large-scale diffusion (Ortt R. , 2012). These proposed strategies fit the stage of the technology development, as well as the technology itself and external factors at the moment of the market introduction (Ortt, Shah, & Zegveld, 2007). An example of a niche strategy was used in the introduction of hybrid cars, which use fuel as well as electricity, to the market. This adaptation strategy enabled the use of fuel-efficient cars (electric and combustion engine) until the infrastructure to use fully electric cars is broadly available (Ortt, Langley, & Pals, 2013).

No systematic evaluation of the barriers to MASS diffusion is available in the current literature. Consequently, a market strategy aiming at overcoming MASS barriers is also not available. The lack of systematic evaluation of the barriers to MASS diffusion hampers the development of a suitable market introduction strategy for this breakthrough technology. The proposed contribution enhances the understanding of MASS diffusion as a breakthrough technology by using the current diffusion models for its analysis. Because this technology is specifically aimed at the maritime industry, the research can help to evaluate the current models and frameworks validity in this specific industry.

1.8 Research Contribution

This study will combine the innovation management literature stream, and the maritime technology knowledge field, possibly adapting current diffusion strategies to the maritime industry context. Its contribution is twofold:

- It contributes to the scientific field by applying available frameworks and models into a breakthrough technology that is currently in its developing state, adding the cargo ships context to the development of niche innovation strategies.
- It also contributes to the managers of the cargo ships industry, offering scientific support for decision making towards the future diffusion of this technology.
- For both, managerial and scientific fields simultaneously, this research contributes by developing potential pathways for MASS diffusion. Bringing a new perspective to the niche innovation strategies for the academic literature and suggesting a logical path for companies offering MASS technology.

The following research question and sub-questions focus on bridging the literature gap and contributing to the scientific and managerial fields of autonomous ships' technology.

1.9 Research Question & Sub questions

"How can MASS reach diffusion within the maritime industry?"

1. What are the characteristics of the current applications of autonomous ships?
2. In which pre-diffusion stage is the autonomous shipping technology?
3. What are the actors and factors affecting the adoption and consequent diffusion of MASS?

4. How could actors and factors hampering autonomous ships be surmounted?
5. What are the potential pathways to remove barriers and capitalize on encouraging factors to autonomous ships technology?
6. How can these pathways be used to facilitate autonomous ships technology diffusion in other application niches?

1.10 Structure of the Report

After the introduction follows Chapter 1 presents the research problem and objective, the literature review, the research contribution, as well as the research questions. Chapter 2 describes the methodology. Chapter 3 presents the context in which MASS technology is developing, explaining the external and internal factors that affect the development of the technology, as well as MASS technology itself. This chapter follows the TIS perspective presented in section 1.4.3 Technological Innovation System (TIS). The overview given by chapter 3 serves as a base for understanding the following chapters and answering research questions 3, 4, 5 and 6.

Chapter 4 answers sub-question 1 by introducing the current MASS applications and concludes with the characteristics of the current application for MASS technologies. Chapter 5 uses the answer to research question 2, adds the historical perspective of MASS, to identify its introduction moment to the market. This chapter concludes by answering research question 2 based on the Pre diffusion model explained in section 1.4.2 Pre-diffusion Model[1]. Chapter 6 presents actors and factors affecting MASS diffusion following the Building Blocks Framework presented in section 1.4.4 Building Blocks Framework[2] and using the MASS literature reviewed in section 1.5 MASS Literature Review Chapter 6 concludes by answering research question 3 by describing the actors and factors affecting the current developments of MASS.

Chapter 7 is divided into 3 sections and answers the 3 remaining research questions. In section 1 it uses the strategies reviewed in section 1.4.5 Technology Introduction Strategiessolutions to overcome the actors and factors hampering MASS diffusion detailed in chapter 6 answering research question 4. Section 2 Builds upon the strategies to overcome the barriers presented in section 7.1 and suggests 2 potential pathways to stimulate the diffusion of MASS, taking the System perspective reviewed in section 1.4.3 Technological Innovation System (TIS) answering research question 5. The third and final section combined the knowledge of sections 7.1 and 7.2 to answer research question 6 showing how the developed pathways can be applied to other application niches. Finally, chapter 8 presents conclusions and discussion. The conclusion compiles the answers to all sub-questions and presents the answer to the main research question, while the discussion develops on the value and limitations of research, the external and internal validity, as well as directions to further research.

2. Research Methodology

2.1 Methodology

Sekaran & Bougie (2016) suggest the use of exploratory research when little is known about the research problem or when the topic is too complex. Therefore, given the lack of specific literature about the innovation management aspect of autonomous shipping previously mentioned in section 1.7 Research Problem, and the complexity of the maritime industry exploratory research is the most appropriate method for the MASS research project. As exploratory research, this thesis relies mostly on qualitative data in the form of unstructured and semi-structured interviews, adding the data available on published literature to answer the research question “How can MASS reach diffusion within the maritime industry?”

A literature review is a selection of published and unpublished available documents on the desired research topic that contains written information about the nature of the topic, showing different views on the nature of the topic investigated. A literature review aims to investigate and evaluate how the available material relates to the desired research topic. It ensures that the desired topic is positioned within the available literature and builds upon available knowledge, as well as helps the thinking process from a specific angle (Sekaran & Bougie, 2016).

The literature review of this research is required to understand the context in which autonomous shipping is being developed, as well as the barriers to MASS technology development already identified in the literature and possible solutions to these barriers. Such focus aims at understanding the factors that prevent the maritime industry from making a transition to autonomous shipping. The literature review makes use of textbooks, conference proceedings, white papers, and scientific articles available at the TU Delft Library database and on the internet. The keywords “Maritime”, “Ships”, “Autonomous”,” Innovation” and “Diffusion” and other terms similar terms.

An interview is a data collection method that allows the researcher to gather a large variety of data from participants. Unstructured interviews do not have a set of planned questions to be asked and focus on bringing preliminary issues to the surface, allowing the researcher to determine the areas that need further investigation (Sekaran & Bougie, 2016). Given the exploratory nature of this research and the broad variety for MASS usage in the maritime industry, the use of unstructured interviews to narrow the focus of the research was deemed suitable.

The data gathered with the literature review and the unstructured interviews narrowed the focus of the research and identified the variables that needed further investigation. Given the novelty of MASS technology and the lack of data regarding the barriers to its adoption by the maritime industry, the use of semi-structured interviews was deemed necessary. Semi-structured interviews are a mix of structured interviews, which have a set of planned questions and the previously mentioned unstructured interview. The goal of this data collection method is to have a specific set of questions for all interviewees, but still allow room for further clarifications questions within the topic. This allows the interviewer to adapt the question list to fit the particular expertise of the interviewee (Saunders, Lewis, & Thornhill, 2016). Therefore, a list of questions was created aimed at clarifying aspects of the literature available and acquire more in-depth data about the MASS topic. The list with all questions, as well as an example summary of the interviews can be found in the Appendix of this report.

2.2 Selection of Interviewees

The unstructured interviews were performed with MASS researchers, employees of companies developing MASS technology and shipyard managers. These professionals were chosen based on their experience on MASS or their understanding of the maritime industry characteristics as per their LinkedIn profile, scientific articles or white papers written about the research topic. They were contacted using social media, or via the website of the companies for which they work. Each interviewee was asked to refer to possible other interviewees, creating a snowball effect.

During the unstructured interviews, interviewees were asked to talk about their work, experience and understanding of MASS, their perspective on the future of the technology and which sectors would have could profit from the implementation of MASS, as well as which areas of technological development seemed easier or more complicated to MASS diffusion.

The selection of interviewees for the semi-structured interviews was made based on the different areas affected by MASS technology, aiming at the diversity of perspectives within the same industry. The only interviewee not connected to the merchant marine sector, the Naval System Integrator, was chosen not only because of his broad MASS knowledge acquired in the MASS joint industry project but also because the Navy is known as the testbed for maritime technology, acting as an innovator, if compared to the diffusion scale defined by Rogers (1985).

In the second round of interviews, not only the initial interviewees were once more questioned but also professionals that will be affected by the introduction of the technology, such as captains, chief engineers, vessel operators and harbour infrastructure specialists. These interviewees were also selected based on their professional experience and contacted using the same methods of the first round of interviews.

2.3 Analysis of the Interviews

According to Saunders, Lewis & Thornhill (2016), qualitative data is likely to have a large volume and a complex nature. Therefore, the analysis involves summarizing, condensing, and categorising the data into themes to make sense of it and link it to the research question. The analysis of the interviews conducted for this report has followed the same path. The interviews were recorded and a transcript was generated by Otter AI, a program that transforms voice into text.

All transcripts were reviewed and summarized based on the relationship of the interviewee opinion to the content of the research. The summaries contain the entire content of the interview, in this phase of the analysis, only the repetitions and language expressions were removed to ensure better reading of the interview content. An exception was made for interviewees that did not permit recording of the interview. In this case, there was no transcript to analyse, and a summary was made based on the notes taken during the interview. The collected data from non-recorded interviewees were categorised similarly to the recorded interviews.

Once the transcripts were ready, they were reviewed according to the content, and codes were assigned to the content of the interviewee comment. Initial codes were based on the 14 building blocks and influencing factors proposed by Ort and Kamp (2021). For the codes that did not suit the categories proposed by Ortt and Kamp, new categories were created. Table 7 - Codes & Categories of data analysis shows the list of codes used to analyse the interviews and categories used based on Ortt & Kamp (2021) framework.

Ortt & Kamp Factors	**Categories of Interviewees factors**	
Quality/ performance	Performance	
Production System	Production System	
Price	Economic	
Network formation and coordination		
Complementary products or services	Complementary	
Customers		
Institutions	Institutions	Regulation
Knowledge and awareness of the technology	Knowledge	
Knowledge and awareness of the application in the market	technology push	
Natural, human, and financial resources	Human Resources	Maritime Knowledge
Competition		
Macro-economic and strategic aspects		

Socio-cultural aspects	Culture
Accidents and events	
	Safety
	Operational

Table 7 - Codes & Categories of data analysis

2.4 Overview of Methodological Approach

Figure 7 presents the data collection method and the method used to answer each of the research questions mentioned in Section 1.9 Research Question & Sub questions of this report.

Case studies and press releases about current MASS applications as well as Interviews.

Categorisation of the characteristics of the current applications through reasoning

Sub-Question 1

Literature about history of MASS technology and its evolution.

Classification of MASS according to Pre-diffusion Model.

Sub-Question 2

Literature about MASS technology development and Interviews.

Categorisation of actors and factors according the Building Blocks Model.

Sub-Question 3

Reports analysing the feasibility of MASS and Interviews.

Categorisation of possible solutions to surmount the barriers using the technology introduction strategies

Sub-Question 4

Consolidation of pathways through reasoning building upon SQ4 answer.

Sub-Question 5

Consolidation of alternative applications through reasoning building upon SQ2, SQ4 and SQ5 answers.

Sub-Question 6

Figure 7 – Specific Methodology for each research sub-question

3. Autonomous Shipping Technology

The organization of this chapter is based on 1.3 Literature Review and explained in section 1.4.3 Technological Innovation System (TIS). According to Bergek et al (2008), it is necessary to understand the technology itself, as well as the external and internal environments in which it is being established to evaluate its development. Therefore, section 1 defines the terms used within MASS and their meaning, to ensure complete comprehension of the technology and its capabilities; sections 2, 3 and 4 explain the technology, the external and internal environment in which it is being developed.

In this chapter, MASS description is subdivided into 4 sub-items: technological principle, functionality, components, and levels of autonomy. Technological principle, functionality, components are used by Ortt & Dees (2018) in a study about breakthrough technologies using the BBF model to evaluate their market readiness. The last sub-item, levels of autonomy, was added to guarantee a complete understanding of the differences between the autonomy levels. This understanding of the 4 above-mentioned technology sub-items, as well as the internal and external environment, is necessary to completely grasp the factors presented in Chapter 6 and the relationships among the factors.

3.1 Terms & Definitions

The understanding of the concepts of autonomy, automation, and decision-making (or reasoning to achieve decision-making) is paramount for understanding the MASS technology. Going back to the Greek roots of the word autonomous, Kooij & Loonstijn (2018) explain that the word is a combination of two Greek words, auto, and nomos which respectively means “self” and “law”. They explain that an autonomous agent can rule over itself and make independent decisions. In line with their definition, Wright (2020) focuses on autonomous vessels, by explaining that autonomy is “the independence or freedom from human influence as a vessel proceeds from point A to point B” (2020, p. 36).

Wright (2020) explains that automation, on the other hand, refers to the use of automatic equipment or processes that enable the vessel to go from point A to point B. While Kooij & Loonstijn (2018) already touch upon the decision-making capability of the autonomous ship when defining autonomy, Wright (2020) refers to it as Reasoning, explaining that “Reasoning provides the capability to coordinate shipboard automation processes to achieve the goals of autonomy” (p. 36).

It is also important to clarify the difference between autonomous and unmanned in the MASS context. While an autonomous vessel can perform a set of specified operations without or with reduced attention from the crew, an unmanned vessel excludes the presence of humans to perform or supervise the operations (Rødseth & Nordahl, 2017). Considering that current ships are already equipped with highly automated systems, the main difference between the conventional and the autonomous ship lays in the decision-making process. While the former depends on the crew, the latter is equipped with an operating system capable of making decisions and determining actions by itself (de Vos, Hekkenberg, & Osiris, 2021).

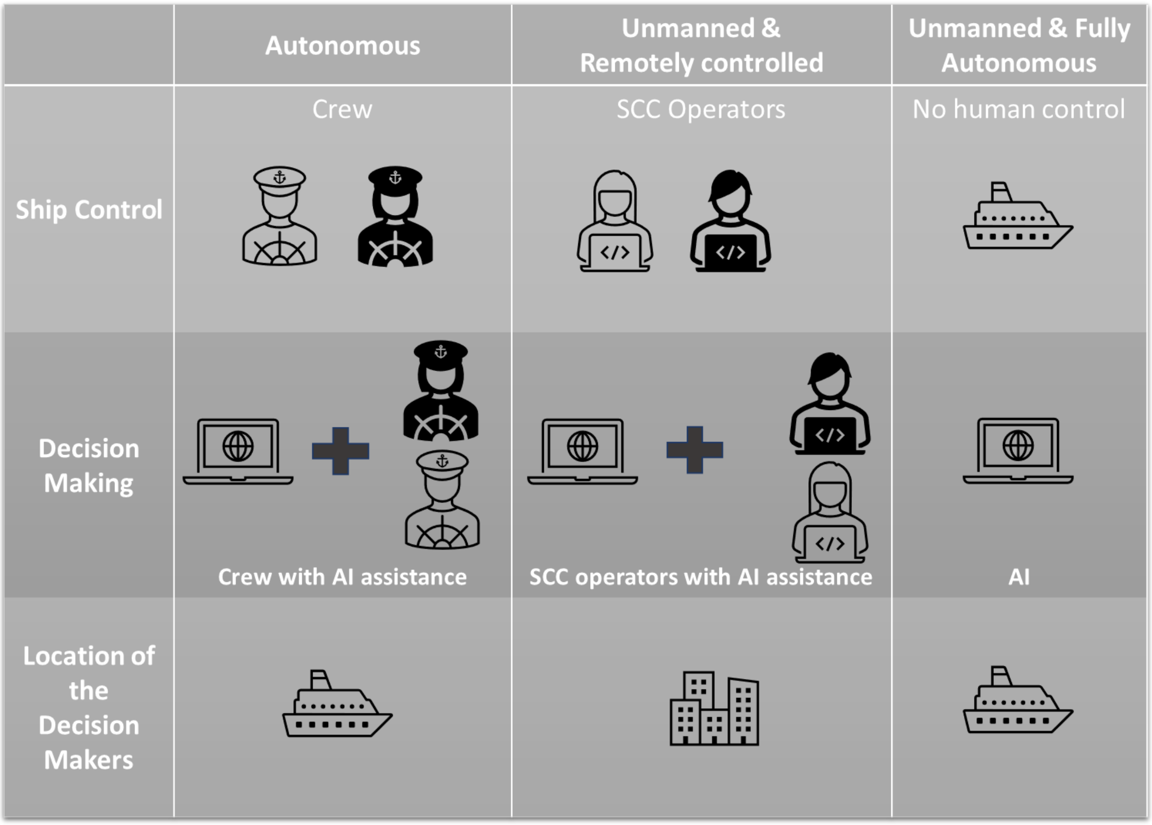

Figure 8 - Autonomous, Remotely Controlled & Unmanned

3.2 MASS

3.2.1 Technological Principle

The operating system mimicking the thought process of seafarers when navigating and solving unforeseen situations on board is Artificial Intelligence (AI), which is defined by the Association for Advancement of Artificial Intelligence (AAAI) as the understanding of the processes that result in thoughts and intelligent behaviour and their embodiment in machines (Wright, 2020). More specifically, the field of artificial neural networks, which simulates the human brain and the thinking processes, is the main AI principle behind the MASS technology.

The concept of MASS technology is similar to self-driving cars, the similarities are so that one of the scales used to measure the autonomy of ships was developed by the Society of Automotive Engineers and it is used to assess driving automation in on-road motor vehicles (Wright, 2020). Self-driving cars are equipped with self-learning software that collects data from their navigation system, sensors that monitor other cars, and sensors that measure the performance of the engines that propel the cars. This software calculates the route using the data input, driving itself through regular traffic without the intervention of a driver (Ortt & Dees, 2018). These systems, named multi-sensor perception systems, are also used for mobile mapping, Unmanned Aerial Vehicles (UAV), robotics, and the maritime context, although the latest one has received less attention so far (Thombre, et al., 2020).

MASS technology is based on Artificial Neural Networks (ANN), a field inspired by neuroscience, more specifically by the studies of brain activity that explain the cognitive processes behind human thoughts, actions, and consciousness (Russell & Norvig, 2010). All ANN's have essentially the same structure: the neurons are organized in one input layer, one or more hidden layers and one output layer (Kooij & Loonstijn, 2018). The number of neurons in each layer, or how they are interconnected depends on the specific problem it needs to solve (Wright, 2020). The properties of the ANN are determined by the organization and the peculiarities of the neurons (Russell & Norvig, 2010). The more neurons and layers, the higher the accuracy and the training time (Kooij & Loonstijn, 2018).

Within the AI perspective, autonomy is related to the ability to learn what it can do and use the "lessons learned" to compensate for partial or incorrect prior knowledge. Therefore, ANN is not programmed but trained, it is constantly learning. Its capability to learn allows it to succeed in an enormous variety of environments (Russell & Norvig, 2010), while a programmed unit would only find solutions that were previously programmed by the developer (Kooij & Loonstijn, 2018).

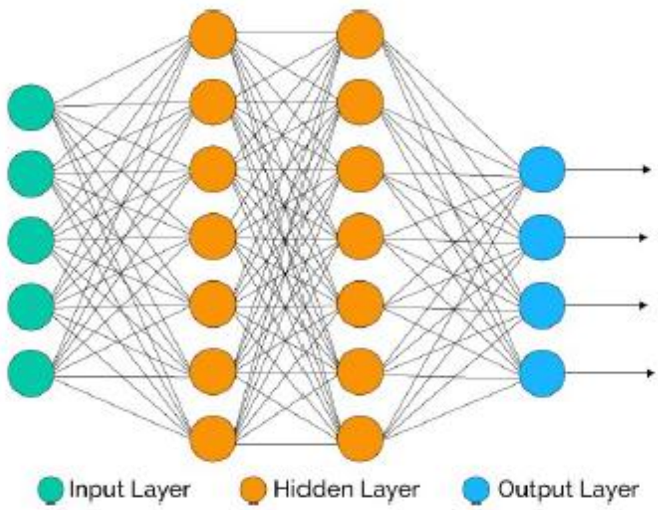

Figure 9 - An Artificial Neural Network (Kooij & Loonstijn, 2018)

3.2.2 Functionality

Vessels can use MASS technology to calculate the best course of action for safe navigation given the environment and the ship's specific manoeuvring capabilities autonomously. To function properly MASS needs enough computing power to process and interpret large data sets coming from the different sensors on board the ship and its surroundings, such as cameras, radar, AIS, engine throttle, rudder position and many others. After treating and interpreting the data, MASS calculates the best course of action given the current environment and signals automation on board to perform the calculated action (Wärtsilä, 2021).

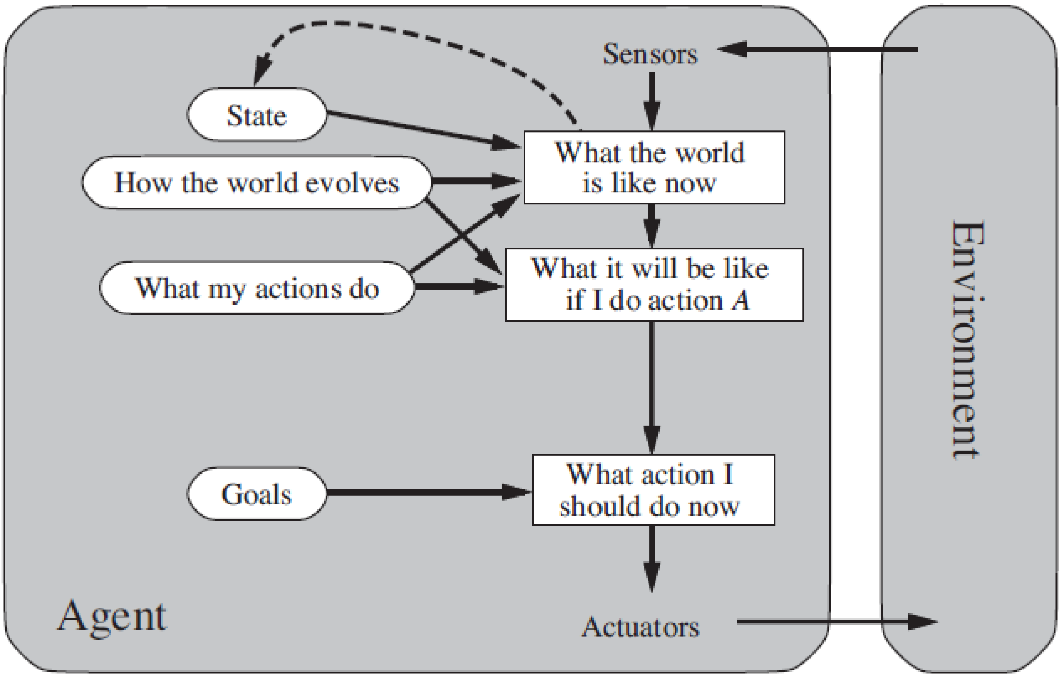

Figure 10 - Intelligent Agent Structure (Russell & Norvig, 2010, p. 51)

To enhance the decision-making capabilities of the crew, or (in the future) completely replace it, MASS needs to master three broad capability areas: Situational awareness; Decision making and logic; Action and control (Wärtsilä, 2021). This is basically what seafarers currently do: detect tasks to be performed, decide on safe action, and take action accordingly. Using MASS technology, the ship will perform these tasks itself, or operators will perform them remotely from Ship Control Centres (SCC) if/when ships become remotely controlled (Ramos, Utne, & Mosleh, 2019).

Figure 11 - Key Capabilities of Autonomous Shipping (Wärtsilä, 2021)

3.2.3 Components

According to the Rules for Classification and Construction provided by Germanishcer Lloyd (2012), the bridge of any seagoing ship must contain specific sensors and equipment to ensure the ship will be allowed to operate according to the maritime regulation, in technical terms, to ensure the ship has a class certificate. The exhaustive list of necessary equipment is not in the scope of this study, neither important for the understanding of MASS, therefore it will not be described here.

For a better understanding of MASS, however, it is important to understand that this mandatory equipment is interconnected and how they are combined affects navigation. Currently, most ships are equipped with integrated bridge systems (IBS), a set of screens and modules that allow one single seafarer to monitor and control navigation, propulsion, and situational information from the navigation bridge. The IBS relies on the information of mandatory navigational equipment including Radar, Electronic Chart Display (ECDIS), GPS positioning, AIS, ARPA, depth sonar and other situational awareness information from the onboard machinery (Wright, 2020).

All this automation is commonplace to modern navigation, and it is made possible by the use of standard data buses and communication protocols. Nevertheless, at present, automation is not yet capable to remove the human lookout, the human eyes (and ears) are responsible for following the COLREGs, identifying other vessels or fixed objects, and maintaining the ship in a safe course according to weather conditions (Wright, 2020). Despite not being able to replace the navigator, automation has reached a level of accuracy that goes beyond human capabilities, as exemplified by the long-haul captain comment.

“I have been sailing a ship on autopilot in a busy canal and I could see the banking effect easily because the rudder was going 20 degrees when it was normally giving 5 or 10 degrees. The helmsman is usually giving too much rudder, regardless of his/her experience. It could be because helmsmen are not too experienced anymore, or because they want effect instantly. The current autopilots are more sensitive and capable of sensing the necessary rudder angle”

(Interviewee 10, 2021)

Concerning situational awareness, different companies offering MASS present different components for their solutions. Shipping Technology (Interviewee 5, 2021) uses the situational awareness equipment already on board, connects it to a “BlackBox” capable of processing all data and this box calculates the best action to be taken, as illustrated in Figure 12. This technology does not intend to replace the navigator, but to give the seafarer a calculated decision suggestion, based on the data collected by the sensors. In the meanwhile, the software learns with every action taken by the navigator, testing its own suggestions and results, to be able to navigate autonomously using the lessons learned of all ships that used this technology.

Other companies have a different focus, the software offered is not on board the ship, but cloud-based. Captain AI is one of these companies, it uses historical open data transmitted by the AIS to create a route planner for every ship, according to its size. For situational awareness, the company uses a camera, Radar and AIS which ensures that the route will be adjusted according to the environment, taking into account the movement of all vessels in the vicinity (Interviewee 02, 2021). Seafar (2021) follows the same concept of Captain AI, using cameras as part of situational awareness. Seafar also offers a Ship Control Centre (SCC) operator to control the vessels from a distance. Both Captain AI and Seafar depend on an Internet connection to perform their activities, which is not the case for Shipping Technology’s solution.

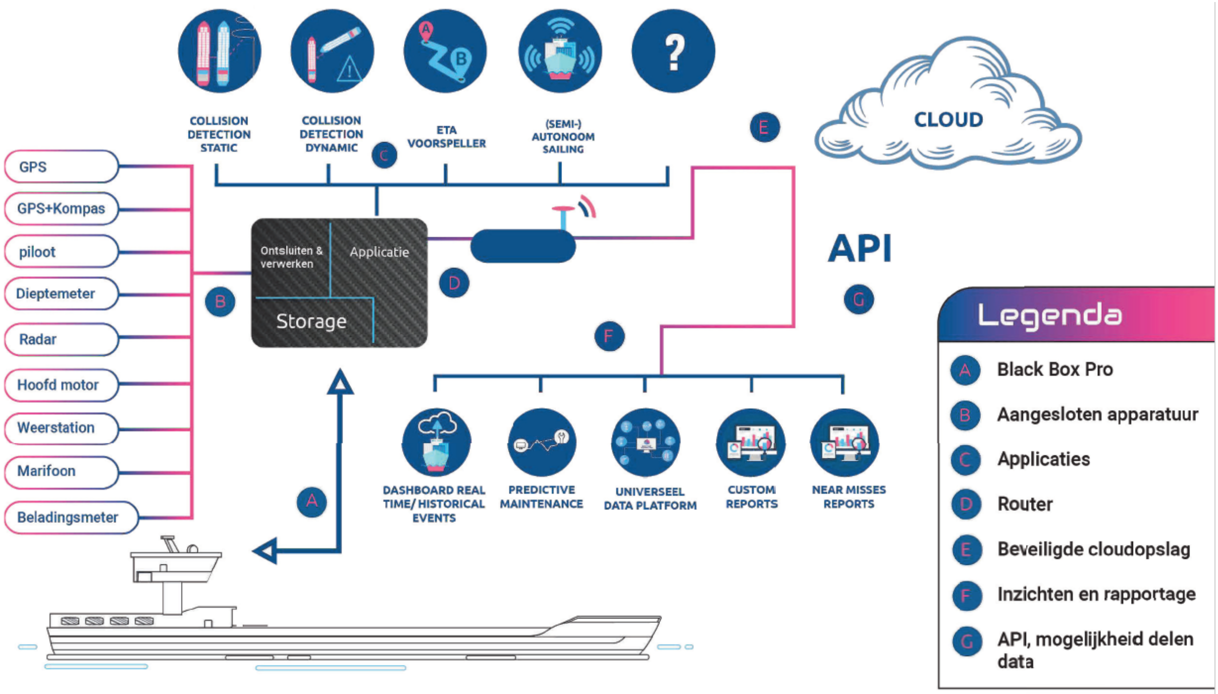

Figure 12- Shipping Technology Black Box Pro (Interviewee 5, 2021)

3.2.4 Levels of Autonomy – Rules & Standards

The autonomy level is not a straightforward definition, in the case of autonomous cars, the Society of Automotive Engineers (SAE) (2021) developed a scale ranging from Level 0: no driving automation to level 6: Full driving automation. The levels in between gradually remove the activities performed by the driver, from assistance to monitoring, from monitoring to only emergency override until the final step in which the human is no longer a driver and no attention or interaction is required.

The maritime industry has not yet reached a standard about the levels of autonomy. The Maritime Safety Committee (MSC) of the International Maritime Organisation (IMO) determined four degrees of autonomy for scoping exercises (IMO, 2018). Despite the existence of a scale created by the IMO, the maritime industry does not follow a standard scale for autonomous surface vessels. Wright (2020) presents five different scales for metrics of autonomy developed for maritime autonomous vessels by different institutions and classification societies. Kooij & Loonstijn (2018) add two more scales in their literature review that were not included in Wright's list. Adding up, there are at least 7 different scales to measure autonomy levels for maritime surface vessels.

The Bureau Veritas (2019) scale of autonomy defines 5 levels of autonomy, from A0 to A4. This scale does not make a level distinction based on how much the operator intervenes in the system and does not add the final level in which autonomous vessels will be completely independent of human control. In level 4, the vessel still has the option of contacting a human operator in case of an emergency. An aspect of the Bureau Veritas scale is the differentiation between degrees of automation and degrees of control, with one scale to measure autonomy and another scale to measure control. This separation increases the possible setups for autonomous vessels and considers both possibilities of onboard control and Remote Control for the same level of autonomy. In this study, any reference made to the level of autonomy of a vessel will consider Bureau Veritas autonomy and control scales as standard, which is fully described in Table 8 and Table 9.

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

Table 8 - Bureau Veritas Degrees of automation (Bureau Veritas, 2019, p. 10)

Degree of control			Human presence	Location of control station
Direct control	DC0	No direct control	No crew available to monitor and control the system, nor to take control in case of warning or alert.	(1)
	DC1	Available direct control	Crew available aboard, ready to take control in case of warning or alert But they may be not at the control station	Aboard
	DC2	Discontinuous direct control	Monitoring and control may be discontinuous during a short period Crew always available at the control station, ready to take control	Aboard
	DC3	Full direct control	System is actively monitored and controlled at any time	Aboard
Remote control	RC0	No remote control	No operator available to monitor and control remotely the system, nor to take control in case of warning or alert.	(1)
	RC1	Available remote control	Operators available in the RCC, ready to take control in case of warning or alert But they may be not at the remote control station	RCC
	RC2	Discontinuous remote control	Remote monitoring and control may be discontinuous during a short period Operators always available at the remote control station, ready to take control	RCC
	RC3	Full remote control	System is actively monitored and controlled remotely at any time	RCC
(1) See also [2.8.3]: there may not be any integrated control station				

Table 9 - Bureau Veritas Degrees of Control (Bureau Veritas, 2019, p. 11)

3.3 External Context

Ships have been crossing oceans for many centuries and have been gradually changing. From sails that harnessed the wind and allowed sailors to discover new lands and trade posts, the ships’ propulsion evolved to steam and later combustion engines. Initially made from wood, iron started to be used to strengthen the hulls decades before the first ship was completely made of iron. Most of these changes did not originate from the sailors or naval engineers, but the knowledge coming from other areas of expertise “spilt over” to the maritime industry, making the ships evolve to the type of ships now commonly seen in the international trade (Wright, 2020).

3.3.1 Autonomous Cars

The automotive industry is very advanced in testing and implementing autonomous cars, smart cars are a growing trend. Beyond the trend is the promise to enhance road safety and congestions by reducing the distance between cars without increasing collisions. Autonomous cars are expected to increase the flexibility and frequency of public transport, as well as reduce wage costs for this service. The technology used for autonomous cars uses RADAR, LIDAR, infra-red cameras and computer vision for situational awareness, a software that receives and interprets all these sensors data and finally decides how to steer and when to break (Blanke, Henriques, & Bang, 2017). The logic for autonomous shipping is the same (Interviewee 02, 2021).

Both technologies share more than the AI logic. Fagnant & Kockelman (2015) mention encouraging factors for the adoption of autonomous vehicles (AV) technology such as safety, reduction of fuel consumption, and reduced need for truck drivers, which will have a positive impact on freight costs. Not surprisingly, these aspects are nearly the same as the encouraging factors for MASS (Rødseth & Nordahl, 2017) (Komianos, 2018) (Wróbel, Montewka, & Kujala, 2017).

Despite having the same logic, the development of autonomous shipping is not fully comparable to autonomous cars because of some very important differences. The first one is that ships are already further automated than the average cars, equipped with situational awareness equipment and capable of maintaining a constant speed (cruise control), as well as following a journey that includes changes in direction without the interference of the navigator. The latest feature is already considered autonomy for cars (Level 1) (SAE, 2021), but not for vessels (Bureau Veritas, 2019).

Another difference is the number of cars versus the number of ships in use. According to Statista (2021), the world merchant fleet has currently nearly 55,5 thousand vessels of different categories, including container ships, general cargo, and oil tankers. Statista also shows that the average age of the world merchant ships is just above 20 years old (Wagner I. , 2021). In 2019, there were 35 million commercial cars and 342,2 million passenger cars only in Europe, both categories with an average age between 11 and 12 years old (ACEA, 2021). This shows that the automotive fleet is much larger than the merchant fleet, making the investment in the former more attractive than the latter.

In addition, the age of the fleet Statista (ACEA, 2021) shows that cars have a shorter lifespan, on average half of a ship lifetime, indicating a faster renewal cycle in the automotive fleet when compared to the merchant marine fleet. The longer lifetime implies that to adopt MASS, vessels must suffer modifications during their lifetime, which can be costly if the equipment does not easily connect to the standards of new technology (Interviewee 02, 2021) (Interviewee 3, 2021).

The complexity of the operation is also another difference factor between cars and vessels. While a driver's license is achievable to most of the population above 18 years old, to become a navigator it is necessary to follow a complete an STCW certified education of 3 or 4 years (depending on the country) and an entire year of practical internship on board denoting that the complexity on operating a vessel is is very higher than driving a car(Galić, Lušić, & Pušić, 2012).

3.3.2 Enabling Technologies Development

MASS is not a technology on its own, similar to many other technological innovations, MASS was made possible by the advance of other technologies in different fields. Kobyliński (2018) states that the capability to collect, process and transmit data from sensors on board to shore stations is paramount to the MASS technology. In this perspective, advances in Big Data Analysis, measurement sensors and the Internet of Things (IoT) are developments that made MASS technology a reality. The author also mentions that the price for data transmission has also achieved a price that makes large data sets transmission financially achievable, increasing the feasibility of MASS adoption, noting the increase of availability and price reduction of wireless internet connections as factors that influenced MASS.

Big Data (BD) is a large data set that allows managers to access new knowledge and improve their decisions and performance, but that is extremely large, diverse and quickly generated to be processed by classical IT solutions (Lacam & Salvetat, 2021). BD solutions are used to process the vast amount of data provided by various sensors on board. Generally, a DB software processes the data before sending it to the Ship Control Centre (SCC), which will use it to control the vessel (Kobyliński, 2018). In other MASS solutions, the data is kept on board and transferred later to the vessel operator (Interviewee 5, 2021).

IoT can be simply defined as the ability of an object to independently collect and exchange data with other devices using its embedded electronics, software, sensors, and network connectivity (Ang, Goh,

& Li, 2016). The value of IoT lays in the possibility of connecting devices that can communicate not only to each other but also to inventory systems, customer support systems business analytics and business intelligence applications. Distinct IoT technologies can be used to deploy a vast range of IoT-based products, Cloud Computing is one of them, which is used in MASS technology developments based on remotely controlled operations (Interviewee 02, 2021).

Lee & Lee (2015) explain that Cloud computing is the basis of the Infrastructure as Service (IaaS), it consists of a pool of computers, servers, storage, and applications that are shared among its users. It has a large storage capacity and massive processing speed to store and process the large amounts of data generated by the sensors installed in the IoT products. These massive amounts of storage and processing capacity enable the real-time use of the BD by the IoT equipment. This data is the input that the MASS system uses to determine the situation (situational awareness) and transmit it to the control centre, where the system calculates a decision and sends the desired action to the ship. For the companies that have cloud-based solutions as Seafar (2021) and Captain AI (Interviewee 02, 2021) this technology is vital.

The emergence of IoT had a large impact on people's lives and working possibilities, the ground Internet, however, does not allow it to realise its full potential. Satellite communication, on the other hand, offers wide coverage, broadly expanding the business scope of IoT (Yang, Zhou, Huang, & Zhou, 2021). Over the last 5 years, satellite communications have decreased in price, the price drop was partially fuelled by the increase of more powerful High Throughput Satellites (HTS), a technological development that increases the volume capacity per satellite without increasing the investment necessary for the satellite operators (Harebottle, 2020).

Beyond the HTS, there is an oversupply in the satellite market, rollouts of new Low Earth Orbit (LEO) constellations by SpaceX and Telesat, as well as other companies offering Medium-Earth Orbit (MEO) satellite connections. Technological improvements in satellite communication allowed operators to reduce costs to about 40% of what they used to be 5 years ago. Given the increased supply in the market, the customer also benefits from cheaper prices, in 2021 the Megabits per second (Mbps) per month is estimated to be around 5 dollars (Harebottle, 2020).

3.4 Internal Context

3.4.1 Crew Shortage

Captain AI considers the shortage of seafarers as an important factor driving the development of MASS (Interviewee 02, 2021). Wärtsilä (2021) mentions the ageing of the population and changes in career aspirations as root causes for a seafarers' shortage soon. Wärtsilä white paper explains that the current pressure is on finding qualified officers with the skillset to operate the vessels efficiently.

Leggate (2007), presents a concern for the quality of the seafarers, but not for the number of crewmembers available, stating that the reduction in OECD maritime officers supply will be compensated by other labour supplying countries. Galić, Lušić, & Pušić (2012) acknowledge the shortage of seafarers but fear the different standards of maritime academies worldwide can affect the quality of officers, posing doubts on the quality of newly graduated officers of some countries.

Qualified crew members are a concern for Dutch companies operating within short sea and inland vessels (Interviewee 7, 2021). The shortage of personnel is an even bigger challenge to the Dutch Navy, encouraging the military institution to adopt technology to compensate for the lack of manpower. Different from commercial companies, crew members of military vessels have a wide range of military training and must be Dutch nationals (Interviewee 14, 2021).

This maritime niche has the opposite problem of the commercial cargo vessels, once the Navy can guarantee the appropriate training, but depends on the aspiration of the population to follow this career. However, the will to work for the military is inversely proportional to economic growth in The Netherlands, meaning that the stable Dutch economy and availability of other work options reduces the interest of the population to work for the Dutch Navy (Interviewee 14, 2021).

3.4.2 IMO Greenhouse Gas Strategy

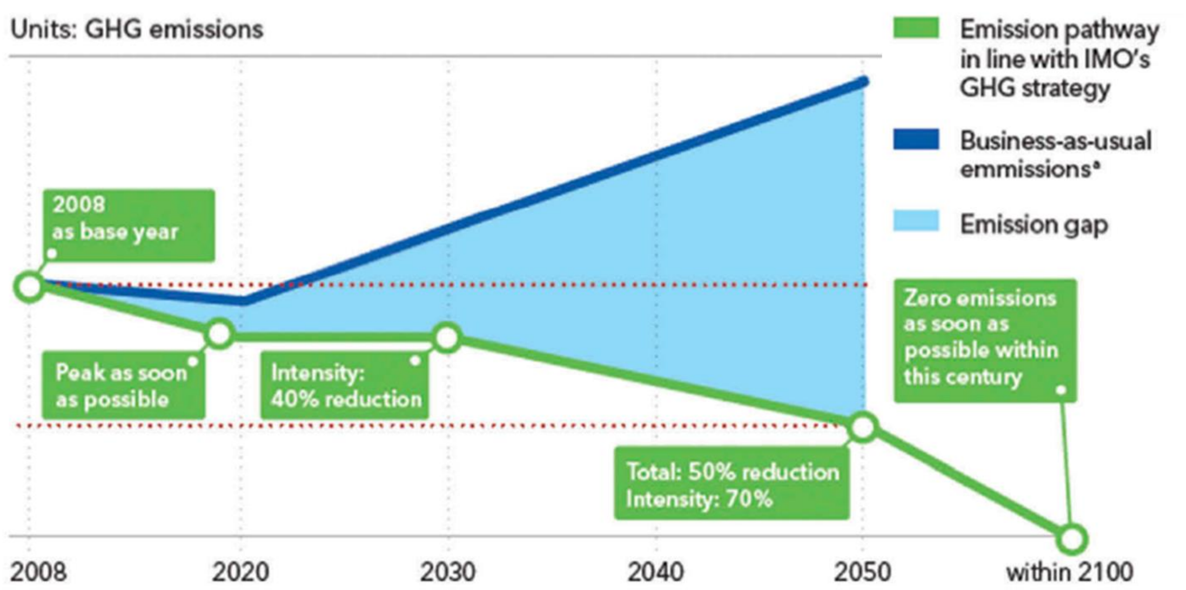

Figure 13 - IMO GHG Strategy (Joung, Kang, Lee, & Ahn, 2020, p. 5)

The IMO (n.d.) has launched a strategy to reduce greenhouse gases (GHG) of international shipping in 2018. According to the IMO GHG strategy, at least 40% of CO2 emissions per transport work should be reduced by 2030, requesting efforts towards 70% by 2050 both based on 2008 CO2 emissions. The target to 2050 aims at a 50% reduction of the total international shipping emissions, also using 2008 CO2 emissions as a baseline. IMO ultimate goal is to be carbon neutral within this century (Initial IMO GHG Strategy, n.d.). The strategy will bring changes to the International Convention for Prevention of Pollution from Ships (MARPOL) in 2022, strengthening the Energy Efficiency Design Index (EEDI).

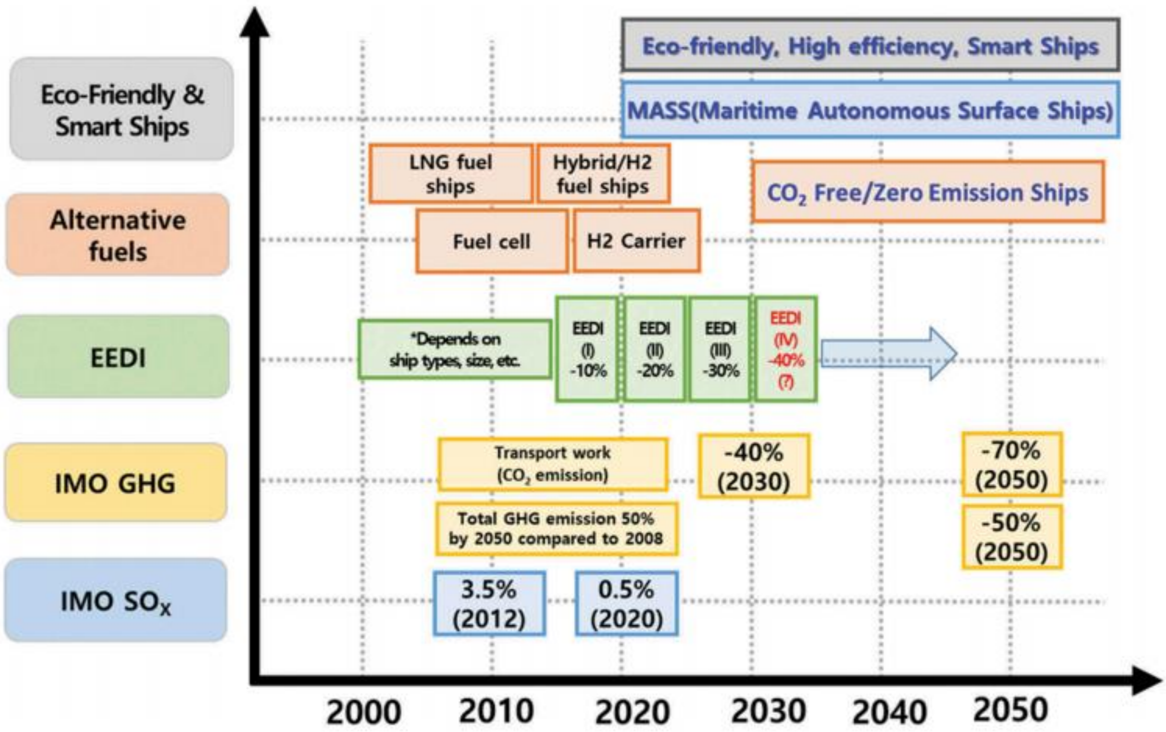

Figure 14 - IMO regulation and ship technology trend (Joung, Kang, Lee, & Ahn, 2020, p. 6)

Joung et al (2020) explain that IMO goals can only be achieved by implementing different measures together. It must be a combination of improved logistics, energy efficiency, speed reduction and fuel changes to reach the 50% reduction threshold by 2050. Among the improvements that can contribute to a reduction of emissions are speed optimization, capacity utilization and voyage optimization, which can be achieved with MASS. Despite not being able to show how the percentage of MASS contribution, the authors consider MASS as part of the technological improvement necessary to comply with the IMO GHG strategy, as is depicted in Figure 14.

3.4.3 Maritime Laws & Regulations

The IMO regulates most aspects of maritime activities, and the Minimum Safe Manning (MSM) is not an exception. The MSM certificate states the minimum number of qualified seafarers required to ensure the safety of navigation, cargo, passengers, and marine environment (IMO, 2011). Whereas the guidelines and principles of safe manning are determined by the IMO (2011), the implementation and supervision of IMO regulations is the responsibility of the country in which the vessel is registered, commonly referred to as flag State (Mansell, 2009).

The flag states assess the MSM and issue a certificate based on the operational condition of the vessel, which considers the type of vessel as well as the level of automation among other characteristics of the vessel (Ministry of Infrastructure and Water Management, n.d.). Because the flag State is responsible, there are differences in safety manning from different flags, some being more flexible than others. In The Netherlands, a viable plan to reduce manning given the adoption of technology is not guaranteed, but it is possible (Interviewee 11, 2021).

Another important concept in maritime law is the definition of Territorial waters, a stretch of water extending from the coastal country until 12 nautical miles (22.2 kilometres) from the coast (United Nations, n.d.). Inside territorial waters, a nation has full sovereignty, allowing the country to legislate any matter concerning navigation, environmental preservation, and pollution control (Hoagland, Jacoby, Schumacher, & Burns, 2019).

3.5 MASS TIS

The characteristics of MASS technology, internal and external environment are paramount for the understanding of Building Blocks, explained in Table *2*and the factors influencing diffusion, defined in Table *3*. These factors are part of the environment in which the technology is being developed, influencing the way the actors interact with each other and ultimately the adoption of the technology.

The development of autonomous cars, as mentioned in section 3.3.1 Autonomous Cars increases the knowledge and awareness of society about autonomy. However, despite the use of the same technological principle, MASS is developed in a completely different internal environment, in which the level of automation is considerably higher and international regulations rule construction, manning and functions onboard. In addition, there are fewer vessels if compared to the number of cars and ships have a longer lifetime than cars. These aspects affect the rate at which autonomy is adopted because of the substitution speed, as well as also the number of companies willing to invest in developing autonomous technology for vessels, given the smaller market for technology application.

The explanation about the technology principle, functionality, and components in section 3.2 MASS shows the complexity of the system and its dependency on learning, instead of being programmed.

This standpoint is important because knowledge of the technology is one of the influencing factors proposed by (Ortt & Kamp, 2021) and defined in Table *3*, which influences the customer's adoption, the safety of the equipment, for example. The specific influence of knowledge of the technology for MASS will be later discussed in chapter 6. Another important aspect is the knowledge about application and market. Therefore, the explanation about the different levels of autonomy and what impact each one of them has in the vessel's operation is an important component for the diffusion of technology. All in all, the aspects mentioned in this chapter are the base of the relationships among the building blocks and influencing factors, showing themselves extremely important in chapters 6 and 7, where the factors and their relationships are used to develop the pathways to MASS diffusion.

4. Current MASS Applications

This chapter shows the current applications of MASS, either as tests or commercially. The understanding of these applications allows a better understanding of the goals of the shipowners when they purchase or test the technology. Understanding these applications sheds a light on the importance of some building blocks and influencing factors, described in Table *2* and Table *3* and helps to determine the importance of the actors and factors for MASS presented in Chapter 6. This chapter also serves as a base for chapter 5, since determining the commercial applications of the technology allow the definition of its pre-diffusion phase. At the end of the chapter, in section 4.4 Characteristics of the current MASS applications, an overview of the characteristics of the current MASS applications is given, answering research question 1.

Currently, there is no commercial application of autonomous shipping in cargo vessels (Interviewee 3, 2021). The many companies working on MASS technology are currently performing tests in different areas of the maritime industry, working with authorizations of Local and national governments in restricted areas (Interviewee 7, 2021). This chapter shows a non-exhaustive list of MASS technology tests, and it is mostly based on knowledge gathered from maritime news and press releases from the companies involved in the testing of the vessels. Since companies use proprietary technology, little is shared about technical details, failures or barriers encountered during the performed tests with MASS technology. The same is true for military applications, the Dutch Navy has performed many tests with MASS technology (Interviewee 14, 2021), but their results are not publicly available.

4.1 Cargo Vessels

4.1.1 Yara Birkeland

Figure 15 - Yara Birkeland (Lewis, 2021)

Undoubtedly the most famous autonomous vessel, the Yara Birkeland was announced as the world's first electric and autonomous container feeder expected to start operating at the end of 2018. The fertilizer company Yara wanted to ensure the transportation of its products in an energy-neutral and efficient manner, following their commitment to feed the world and protect the planet. To replace the daily 100+ diesel trucks travelling from the factory plant to 2 Norwegian ports, Brevik and Larvik, Yara partnered with Kongsberg to develop the first autonomous vessel (Yara, 2017).

Kongsberg, a leading maritime technology company, became Yara's partner responsible for delivering the technological solution to produce the Yara Birkeland, including sensors, propulsion system, batteries and the control systems that would make the vessel one of its kind (Kongsberg, 2017). Yara Birkeland was equipped with a detachable bridge with navigation and manoeuvring equipment, which is expected to be removed when the ship is ready to sail autonomously (Kongsberg, n.d.).

The vessel is expected to operate within 12 nautical miles (22.2 kilometres) from the Norwegian coast (Kongsberg, n.d.), a stretch of water legally termed Territorial waters (United Nations, n.d.) explained in section 3.4.3 Maritime Laws & Regulations. In these so-called territorial waters, a nation has full sovereignty and does not have to comply with IMO rules (Hoagland, Jacoby, Schumacher, & Burns, 2019). It is within the Norwegian territorial waters that the Yara Birkeland is set to sail exclusively loaded with Yara's cargo. The vessel's route comprises 3 ports with a maximum distance of 30 nautical miles (55.6 kilometres) to each other. To maintain safety, 3 control centres will handle emergencies, condition and operational monitoring, decision support, as well as surveillance of the ship and its surroundings (Kongsberg, n.d.).

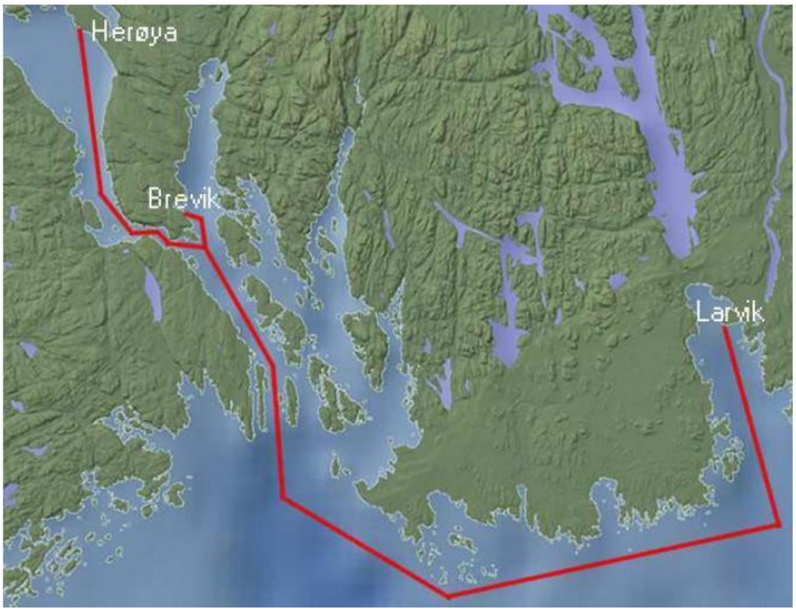

Figure 16- Operational Area Yara Birkeland (Kongsberg, n.d.)

The 120 TEU open-top feeder was delivered to Yara in November 2020 given delays caused by the Covid-19 pandemic (Rowles, 2020). However, the vessel is not yet autonomous. Yara Birkeland must undergo tests for its stability and container load, as well as test voyages in the operational area before the beginning of its autonomous operation. In addition, Yara has found difficulties in the autonomous part of the innovation project, particularly the logistics on land, which made simpler solutions necessary (Buitendijk, 2020). At the beginning of June 2021, Yara Birkeland was laying alongside waiting for the new port construction at Yara's factory at Herøya, Norway, while work was still ongoing on the autonomy level. At the end of 2021, the vessel is expected to start its operation with reduced manning and gradually achieve the level of unmanned operation during the next 2 years (Hellenic Shipping News, 2021).

4.1.2 Vistula Maersk

Figure 17 - Vistula Maersk (Marine Traffic, 2021)

The ice-class feeder Vistula Maersk, constructed in 2018, looks like a conventional container ship, but it is not. It is, perhaps, the future conventional vessel. The ship is 200 metres long, 36 metres wide and can transport 3600 TEU (Marine Traffic, 2021). What sets the Vistula Maersk apart from other ice-class feeders, is the equipment installed on board. Equipped with sensors, LiDAR and computer vision that continuously monitor the environmental surroundings, the system on board Vistula Maersk uses Sea Machines AI software to identify and track potential conflicts. The data is displayed to navigators on the bridge, aiding their decision making (The Motor Ship, 2018).

Maersk's action to install autonomous equipment in one of its vessels seems controversial. Months before Vistula Maersk delivery, in February 2018, Maersk CEO Søren Skou told Bloomberg that he did not expect large container vessels to be allowed to sail without humans on board, it would not be a driver of efficiency, not in his lifetime (gCaptain, 2018). However, it is not controversial. After closing the contract with Sea Machines, Maersk Senior Innovation manager Michael A. Rodey explained the situational awareness tests intended to increase safety, efficiency, and reliability to manned vessels, not turn them into autonomous, neither unmanned (Sea Machines, 2018).

The International Convention for the Safety of Life at Sea (SOLAS) Chapter V regulates that vessels constructed after 1998 must have clear visibility from the navigator’s position. Such standard is specified by minimum visibility in meters, angle of sight and types of windows (SOLAS, 1974). This design restriction brings another perspective to the use of situational awareness equipment on board container vessels. According to The Motor Ship (2018), the use of situational awareness technology on board is to evaluate if the technology can replace the line-of-sight and end the restrictions from the bridge location and design. The end of line-of-sight restrictions would allow a different design to container vessels, possibly increasing the maximum load while still providing infra-structure for a collision-avoidance system.

4.1.3 Factofour

Figure 18 – Factofour (Ship Spotting, 2015)

Factofour is a Dutch container feeder capable of carrying 498 TEU (Shipping Factory, n.d.) that is currently being tested with the equipment provided by Shipping Technology to become an autonomous vessel. The initial test in 2018 was successful and Factofour could steer itself in the inland waterways underway to Volkerak locks in The Netherlands (Shipping Technology, 2018).

The vessel is fitted with the BlackBox Pro equipment offered by Shipping Technology and it is on board this vessel that the AI used in the equipment learns to improve with decision-making capabilities using the behaviour of the captain on board the vessel. The data collected from BlackBox Pro is then filtered to ensure AI will not learn undesirable behaviour in case the captain had to perform manoeuvres that were not advisable (Interviewee 5, 2021). The ultimate goal of Shipping Technology is not to replace the crew, or the captain, but to ensure the team has more time to perform other tasks on board. Hence, the goal of the company is to reduce the crew and therefore reduce operational costs for the shipowners using the BlackBox Pro (Interviewee 7, 2021).

Factofour is also presenting a reduction in fuel consumption and CO2 emissions. This data is not yet statistically confirmed, and therefore not publicly announced, but the data collected so far in the vessel trials show a clear trend towards a cleaner and cheaper navigation style. That is positive for the cost reduction in fuel, but also to comply with the new IMO efficiency standards (Interviewee 5, 2021) (Interviewee 7, 2021).

4.2 Harbour Tugs

4.2.1 Svitzer Hermod & Recotug Project

Figure 19 - Svitzer Hermod

In 2017 the towage operator Svitzer demonstrated the remote operation of the 28 m harbour tug Svitzer Hermod in Copenhagen Harbour, Denmark. During the test, the captain operated the tug from Svitzer headquarters performing common manoeuvres such as berthing the vessel alongside and turning 360°. The MASS technology provider was Rolls-Royce, which installed a Rolls-Royce Dynamic

Positioning System, as well as a range of sensors to ensure situational awareness and the tug linked to the SCC. The SCC did not imitate the design of a control bridge but used input from experienced captains to have a design focused on offering maximum confidence and control to the captain controlling the vessel remotely (Rolls-Royce plc, 2017).

In 2019, Rolls-Royce Commercial Marine, the maritime branch of Rolls-Royce was sold to Kongsberg, transferring all the employees, as well as projects to Kongsberg (Kongsberg, 2019). Only in 2021, Svitzer announced the joint development of the Recotug, a remotely controlled tugboat based on the experiences acquired by the tests performed with the Svitzer Hermod in 2017. The goal of future developments is to improve safety, efficiency and offer cost-efficient services to Svitzer customers (Svitzer, 2021).

4.2.2 IntelliTug Project

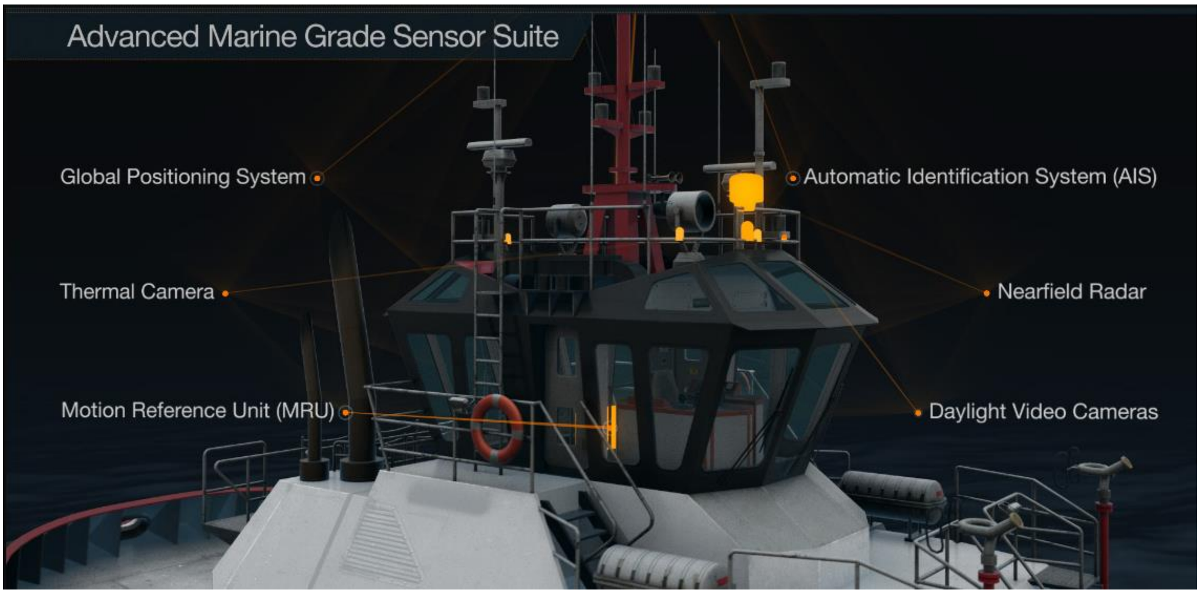

Figure 20 – IntelliTug (Wärtsilä, n.d.)

The IntelliTug project is a joint project with Wärtsilä, the technology developer, PSA Marine, the tug operator, and the Maritime Port Authority of Singapore, among other partners. The project entails the use of technology on board tugs to boost safety, as one of its goals. For one year, the IntelliTug project tested the MASS system to enhance the Tug Master’s capabilities. The tests did not involve remote operations or full autonomy but the use of enhanced situational awareness to assist the crew, allowing harbour masters to focus on operations, while MASS technology maintained the tug in a safe position. According to Roger Holm, Wärtsilä Marine Business President, the goal is to use technology for augmenting the human role on board, not replacing it (Wärtsilä, n.d.).

4.3 Ferry

4.3.1 Falco

Figure 21- Falco (Rolls-Royce, 2018)

Rolls-Royce (later acquired by Kongsberg) (Kongsberg, 2019) and Finferries, the Finish ferry operator demonstrated an autonomous car ferry operation from Parainen to Nauvi, in Finland, a 1,5 nautical miles (3,3 kilometres) voyage (Schuler, 2018). The autonomous voyage took place in December 2018 with 80 passengers on board and no crew intervention. During the return trip, the vessel was remotely controlled by the SCC operators located 50 km away in Turku city centre. During the test, the vessel could alter course to avoid collision and dock itself without human intervention (Rolls-Royce, 2018). The 53.8 metres long vessel was built in 1993 and modified by Rolls-Royce to become autonomous (Schuler, 2018). No further information about Falco was made publicly available since its maiden voyage in 2018.

4.4 Survey Vessels

4.4.1 Mayflower

Figure 22- Mayflower Autonomous Ship (World Economic Forum, 2021)

The original Mayflower set sail in 1620 from Plymouth to the United States of America with passengers in search of a new life across the ocean. These so-called Pilgrims that took the Voyage aboard the Mayflower influenced the future of the USA in many ways. Nowadays, more than 30 million people find one of the 102 passengers and 30 crewmembers in their family tree. This vessel became a symbol of freedom and humanity (Mayflower 400, 2020).

To invoke the pioneering spirit of the renowned vessel, a futuristic autonomous vessel, powered by AI, relying on solar energy and designed to collect oceanographic data was also baptized Mayflower. The new mayflower was reimagined into an unmanned vessel, counting on state-of-the-art technology from IBM and Promare, a marine research institute (Mayflower, n.d.).

Equipped with 6 AI cameras, and more than 50 sensors, the 15 metres long and 6.2 metres wide light-weighted Mayflower set sail on the 15th of June 2021 from Plymouth to reach the USA (IBM, 2021). The ship, however, did not reach its destination. After completing 10% of its journey, about 560 kilometres from Plymouth, the Mayflower was programmed to sail back to its home base. It was not clear what went wrong, according to the Promare director, they did not know what happened, but out of excessive caution, they decided to turn the ship around back to where it started (Brown, 2021).

Three days after departure, the researchers monitoring the Mayflower noticed the vessel was operating at half of its design speed, but they could not detect the reason why. The cameras pointed at the internal components did not capture what was the problem (Brown, 2021) and the multi-million-pound investment project of Plymouth University (Ship Technology, 2021) turned back to start again as soon as the problem was discovered and solved (BBC News, 2021).

4.4.2 Fugro Blue Shadow & Blue Essence

Figure 23 - Fugro Blue Essence & Blue Shadow (SMASH, 2021) (Fugro, n.d.)

Blue Shadow is an unmanned commercial hydrographic survey vessel designed and offered by Fugro. The 8.9 metres long and 1.8 metres wide vessel is equipped with radar, weather station and 360° camera. Its software can avoid obstacles and keep the vessel stable for high-quality data acquisition. In addition, Blue Shadow is also equipped with high-performance sensors for improved hydrographic data quality. Its simple launch-and-recovery capabilities ensure efficiency in the process of deploying it from the mother ship to the water. The Blue Shadow can be operated autonomously, semi-autonomously or remotely operated (Fugro, n.d.).

Blue Essence is slightly bigger than the Blue Shadow (11.8 metres long and 2.2 metres wide) and it can be used for inspection, construction, hydrographic and geophysical surveys. The remotely operated vessel transmits real-time data to Fugro Remote Operation Centre (ROC), allowing it to be operated from any ROC in the world. The Blue essence can be containerized for easier mobilization, and it is equipped with the same easy-to-launch system as the Blue Shadow (Fugro, n.d).

4.4.3 Sounder

Figure 24- Sounder (Kongsberg, 2020)

Kongsberg Maritime also offers a commercial unmanned survey vessel, named Sounder. The vessel is 8 metres long and 2.2 metres wide, designed to be an optimal platform for a hydroacoustic survey, its applications range from fish finding to seabed mapping. Sounder is easily containerized to ensure efficiency in its deployment and it can be remotely operated directly or perform supervised autonomous operation (Kongsberg, 2020).

Aker BioMarine is one of the companies enhancing its operations by using Sounder. In addition to the efficiency of operations, Aker BioAMrine focuses on reducing the carbon footprint of its fishery operations. According to the company, the reduced fuel usage provided by the Sounder will help the company achieving its net-zero carbon emissions by 2050 (Konsgberg, 2021).

4.4 Characteristics of the current MASS applications

The current applications were all performed in a controlled environment, including the commercial survey vessels that are not capable of operating freely in open waters. The only tentative, the Mayflower, was unable to perform its mission, changing its course back home less than a week after leaving the harbour. Because open waters are complex and unpredictable, the ability or inability to operate in open waters demonstrates the quality and performance of the technology. In turn, this capability affects the interest of the companies focussing on unmanned solutions.

The successful tests were performed in territorial waters, or within the authority of harbours, which shows the role regulations have in MASS applications. Because it is easier to achieve governmental permission for tests in territorial waters (Interviewee 14, 2021), since territorial waters only need the permission of the local government, as explained in section 3.4.3 Maritime Laws & Regulations. This perspective shows that the lack of regulation affects the tests and applications of MASS, as will be further discussed in section 6.1.7 Innovation Specific Institutions.

This apparent inability of operating in open waters poses a barrier to long-haul vessels, regardless of their cargo type, given the open-seas nature of their voyages. Another hampering factor for the adoption of MASS in the long-haul sector is the financial attractiveness, further discussed in section 6.1.2 Price. The crews in these types of vessels have minimum impact on the costs of the vessels' operation (Interviewee 10, 2021) (Interviewee 14, 2021). Therefore, investing in MASS is (still) unattractive to the sector.

The MASS tests and applications show differences in what the companies would like to achieve with MASS technology implementation, outlined in Table 10 - Autonomy Goals. While some projects focus on handing the complete control to SCCs, eliminating the crew from the vessel, exemplified by Yara Birkeland, Svitzer Hermod and the Recotug Project. Other focus on operational efficiency, respectively the IntelliTug and efficiency to achieve crew reduction the Factofour.

The Survey vessels, in addition to the complete removal of the crew, can streamline their design, because the crew onboard these vessels is the only reason for their increased size. Full autonomy allows the removal of the complete crew accommodation, making the new design cheaper and more efficient (Interviewee 13, 2021). Finally, the Vistula Maersk, which neither focus on crew reduction, nor better efficiency of the crew, but on the possibility of changing the ship design, exempting the bridge from the line-of-sight restrictions, possibly increasing the number of containers stacked on the main deck.

Category	Vessel	Autonomy Goals
Cargo Vessel	Yara Birkeland	Unmanned autonomy SCC Control
	Vistula Maersk	Increase cargo onboard Fully manned operation
	Factofour	Increase Efficiency Reduce Manning
Harbour Tug	Svitzer Hermod &	Unmanned autonomy SCC Control

	Recotug Project	Unmanned autonomy SCC Control
	IntelliTug	Increase Efficiency
Survey Vessel	Mayflower	Unmanned autonomy
	Blue Shadow & Blue Essence	Unmanned autonomy SCC Control
	Sounder	Unmanned autonomy Local Remote Control

Table 10 - Autonomy Goals

Besides the IntelliTug, which focuses only on increased efficiency, all tests and applications show direct cost-saving by removing or reducing the crew, or indirect, by increasing the amount of cargo allowed onboard. Therefore, they all focus on financial benefits as a goal. This aspect is important because it shows the importance of profit maximisation within the industry, which affects the relationship between the building blocks and influencing factors, further discussed in chapter 7.

The financial focus is exemplified in the differences between the autonomy goals for the Factofour and the Maersk Vistula. The Factofour is an inland vessel, a sector that currently suffers from personnel shortage, increasing the cost of labour for these vessels (Interviewee 7, 2021), decreasing their already limited profit margin. MASS enables the company to reduce 1 crew member, if regulation allows manning reduction, therefore reducing operating costs. The Maersk Vistula, on the other hand, despite being a feeder, is a larger vessel able to carry much more cargo, making the cost of the crew unimportant to its operating costs (Interviewee 14, 2021). Therefore, the company aims at increasing the cargo onboard, not reducing costs, but increasing revenue, another way of maximizing profits.

5. MASS Pattern of Diffusion

This chapter presents the history of MASS, from its invention up to the current commercial developments, including the year in which it was launched as a commercial product. The goal of this chapter is to determine the MASS pre-diffusion phase based on the PDM, explained in section 1.4.2 Pre-diffusion Model[1]. The PDM determines the diffusion phase of technological innovation based on 3 milestones: Invention, Introduction, and large-scale production and diffusion. The definition of the MASS pre-diffusion phase not only answers research question 2 but also serves as a base to the pathway to diffusion, which is developed in chapter 7. As previously clarified in sections 1.2 Research Objective and 1.1, MASS is not yet a diffused technology, which explains why the analysis of the technology in this chapter is done using the PDM, and not another innovation model.

5.1 History of Autonomous Shipping Technology

The history of shipping itself is approximately 5000 years old. Since the ancient civilizations, especially Greeks, Romans and Egyptians, humans have explored a wide range of materials to build and navigate vessels. Since then, the purpose of shipping did not change much: transport of people and goods, fishing, and warfare. The same cannot be said by the materials used to build ships, their structure and propulsion system. From cotton sails to diesel engines and from general cargoes to container vessels, seafarers worldwide have seen their vessels change in their long history (Lavery, 2017). The change to autonomous is merely a new chapter in this ancient mode of transport.

5.1.1 The beginning of the MASS concept

The futuristic idea of remotely operating a boat was patented in 1898 by Nikola Tesla (1919). In his autobiography, the inventor describes his demonstration of the new principle to the audience, where he asked the audience to ask questions and made the automation answer the audience with signs. “This was considered magic at that time but was extremely simple, for it was myself who gave the replies by means of the device.” (Tesla, 1919, p. n/a).

Tesla explains that it was only possible to control the boats within the view range of the operator, but that it should be possible to improve the automation beyond the limits of the vision, at great distances from a centre of control. Tesla also predicted these boats would be capable of having their own intelligence (Bertram, 2016), making Nikola Tesla the inventor of the autonomous shipping concept

(NFAS, n.d.). Despite the very early concept, Tesla himself stated there were no instruments available to achieve remote operation in a precise manner (Tesla, 1919).

5.1.2 Autonomous Shipping Research & Application

It was only in the 1980s that remote control ships started to be investigated in Japan with the Highly Reliable intelligent ship project (NFAS, n.d.) (Bertram, 2016). The concept of the Japanese Intelligent ship was based on the idea of one fully manned mother vessel followed by slave vessels (Bertram, 2016). This concept is known today as Vessel Platooning or Vessel Train, similarly to the Japanese concept, it is a fleet consisting of one fully manned lead vessel that takes over navigation, communication and situational awareness tasks while the remaining vessels follow its lead (Colling & Hekkenberg, 2019).

With the idea of a remotely controlled vessel, either from shore or from another vessel at sea, researchers and fiction writers started to describe the foreseeable future (Bertram, 2016), or investigate it in-depth, such as the study performed by Kaeding & Bertram (1996) which concluded that the autonomous ship was not economically attractive due to maintenance and reliability issues.

In 2006 the Maritime Safety Committee (MSC) of IMO developed the system of e-navigation, which was defined as "the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment." (IMO, 2006, p. n/a). The objectives of e-navigation were to enhance safety, ensure proper application of information technology within the maritime industry and increase the efficiency of transport, as well as fuel usage reduction (IMO - MSC, n.d.). As it would be later explained by Burmeister et al. (2014), e-navigation goals could be achieved by the implementation of MASS technology.

In 2012 the project Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) started with the aim of developing and verifying a concept for an autonomous ship, in which it defined an autonomous ship as “a vessel primarily guided by automated on-board decision systems but controlled by a remote operator in a shore control station” (MUNIN, 2016, p. n/a). MUNIN analysed the feasibility of MASS technology in a wide range of perspectives, such as navigation, shore control centre, new designs and the engine room, among other aspects. This 3-year project has laid the grounds for many studies that would come later about MASS, exploring the (then) capabilities of the technology and indicating the need for further research in specific areas.

The first commercial application using MASS was offered to the market in 2019, the survey vessel Sounder (Kongsberg, 2020), detailed in section 4.4.3 Sounder. Besides this and the later introduced

Blue Shadow and Blue Essence, reviewed in 4.4.2 Fugro Blue Shadow & Blue Essenceall the other known applications are pilot projects or tests, not being characterized as "of the shelf" products available for customers purchase.

5.1.3 Dynamic Positioning contribution to Autonomous Shipping

It is not only the idea of Autonomous Shipping that has been present for a long time, modern ships equipped with Dynamic Positioning have control functions that could be characterized as autonomous (Ramos, Utne, & Mosleh, 2019). Dynamic Positioning (DP) is a technology that was first applied in the 1960s in the oil & gas industry with the sole focus of being used during drilling, diver support and cable laying activities (Kumar, 2020). The main purpose of DP is to maintain the vessel position and heading in a fixed location or follow a pre-determined track using only active thrusters (Sørensen, 2011). In a very summarized description of its functionality: the DP system collects data from environmental sensors, position sensors, power generation and propulsion systems, processes these data in a controller station on board and determines the actions necessary to maintain the vessel in position or follow a track according to the limits established by the operator (Kumar, 2020).

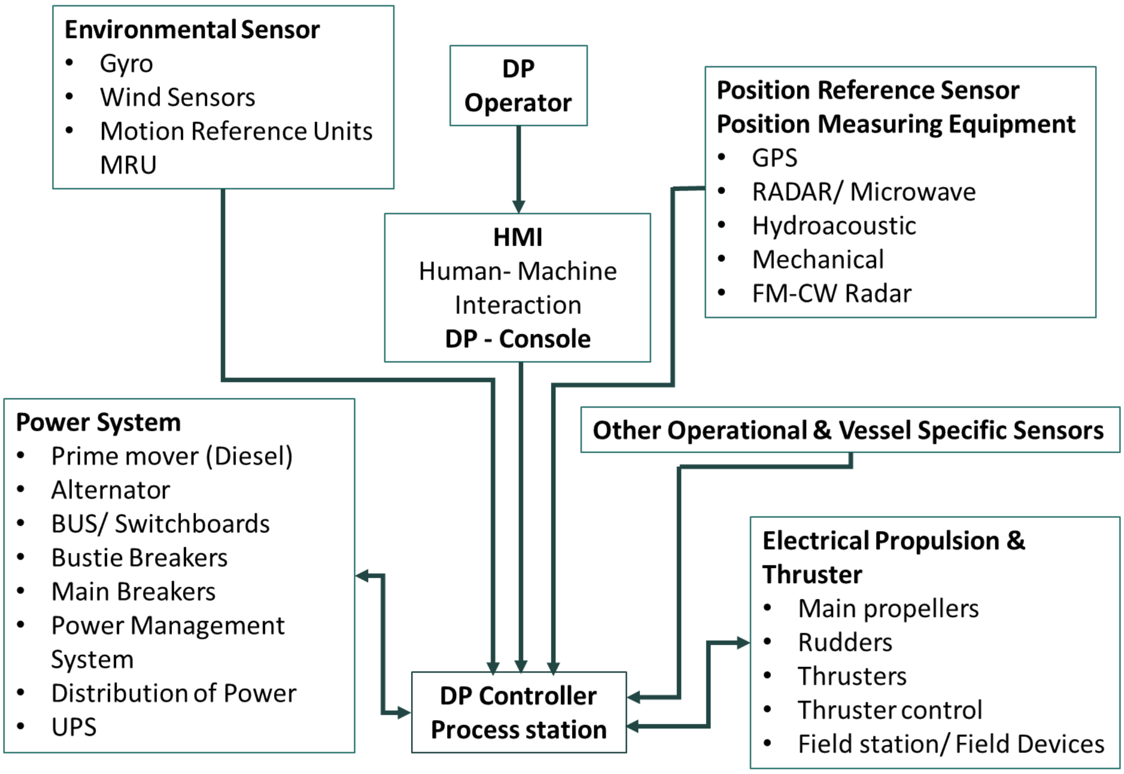

Figure 25 - The seven components of a DP System (Kumar, 2020, p. 14)

Wärtsilä (2021), a large and established maritime equipment supplier that is currently investing in MASS solutions, mentions that autonomy in navigation comes from two distinct sources. On the one hand is the logic of dynamic positioning and autopilot already present in vessels, which are capable of holding course and/ or location cancelling out irrelevant factors. On the other hand, is AI, which can bring ECDIS, radar and simulation into the already existing logic of DP.

The same company offers an Advanced Intelligent Manoeuvring (AIM), which helps Vessel Traffic Management stations in collision avoidance. This system is based on the IMO COLREGs and real-life experience on how ships behave (telemetric), and if connected to ECDIS, it could theoretically steer a ship (Wärtsilä, 2021). The combination of AI, DP and AIM is the groundwork of MASS technology.

Kongsberg, a well-known maritime equipment supplier and the largest ship simulator manufacturer, follows the same logic from DP to MASS technology. The company combines its know-how about DP, simulations, system integration with a radar-based collision avoidance developed in-house to offer the initial steps of MASS technology to its customers (Konsgberg, n.d.). Kongsberg took the MASS development to a further level by creating a joint venture company in partnership with an established shipping group, Wilhelmsen, Massterly, with a mission of implementing MASS technology in short-sea shipping, shifting the cargo transport from the roads to the sea (Massterly, n.d.).

Despite the large investments of many companies in MASS technology, there is no commercial cargo ship operating with the technology at the moment. Many tests are happening worldwide, including tests of the technologies developed by Kongsberg and Wärtsilä, mentioned in chapter 4.

5.2 Where is MASS Technology in the Pattern of Diffusion

In his model, Ortt (Understanding the pre-diffusion phases, 2010) defines three milestones for the pattern development of technological innovation: invention, market introduction and large scale production and diffusion, fully outlined in section 1.4.2 Pre-diffusion Model[1]. The period between the invention and market introduction is the so-called pre-diffusion phase, which is also divided into two sub-phases, the innovation, and the adaptation phase. The innovation phase is the period between the invention of the technological principle until the market introduction, while the adaptation phase takes place between the market introduction and the large-scale industrial production.

MASS technology initial concept dates back to 1898, however, this date cannot be characterised as an invention because the technological principle from that period was not the same as MASS is today. Section 3.2.1 Technological Principle explains that MASS has AI as its basic principle, more specifically, ANN, which mimics the human brain in the decision-making process and learns with data, instead of being programmed. Since this technological principle was not yet used for MASS in 1898, this date cannot be characterised as an invention date.

In 1980, the Highly Reliable intelligent ship project was presented by the Japanese, which indicates the use of artificial intelligence to the mother-vessel concept presented at that time. Despite not being possible to prove the use of AI in that project, its use is highly possible, since AI dates back to 1943 (Russell & Norvig, 2010). Therefore, despite not being fully proven, given the lack of documentation, it is likely that MASS was invented in 1980. It was only 39 years later, in 2019, that the first survey vessel was put for sale for the market specifically for survey vessels. Given the determination of the Invention and Introduction, but the lack of large-scale production and diffusion, it is possible to infer that MASS is in the adaptation phase of the pre-diffusion phase, as depicted by Figure *26*.

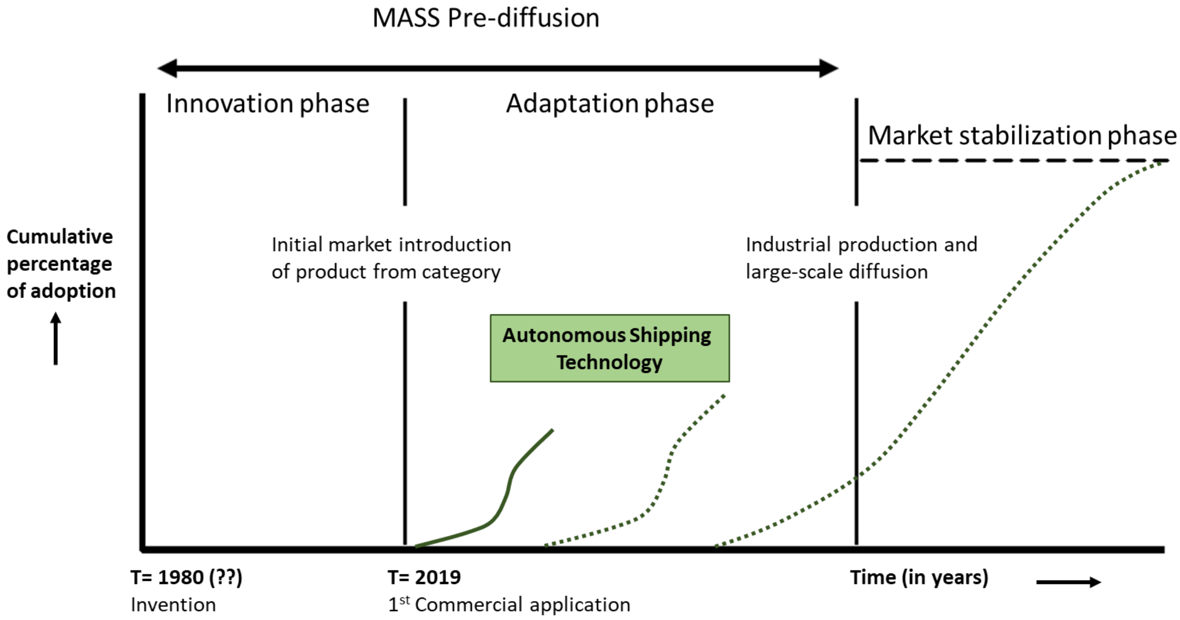

Figure 26- Autonomous Shipping Diffusion Phase

6. Factors Affecting MASS Diffusion

This chapter is divided into 3 sections, Building Blocks, Influencing factors and an Overview of factors affecting MASS. Sections 1 and 2 describe the building blocks and influencing factors affecting MASS respectively, explaining the factors identified by the interviewees within the categories proposed by Ortt & Kamp (2021) explained in section 1.4.4 Building Blocks Framework².

The factors identified by the interviewees were classified and, where suitable, categorised within the BBF. Where the factors did not fit within the BBF categories, a new category was created to accommodate them, as explained in section 2.3 Analysis of the Interviews. Finally, section 6.3 Factors Affecting the MASS adoption presents an overview of the Building Blocks and the Influencing factors for MASS, including the factors that were identified by the interviewees, but were not part of the BFF. This overview is used to answer research sub-question 3 “What are the actors and factors affecting the adoption of MASS?”

The interviewees proposed factors affecting MASS in its complete range, including manned, unmanned, locally or remotely controlled. While most factors are relevant for all autonomy levels, others are only important for unmanned vessels. Therefore, factors in this chapter are to be considered for all MASS autonomy levels and degrees of control, unless otherwise specified.

The differences between autonomous and unmanned were detailed in sections 1.3 and 3.1 but it is valid to recall that the difference lays in the degrees of control, suggested by Bureau Veritas (2019). Autonomous vessels are equipped with Direct Control (DC) degrees 1 to 3, in which the operator is on board the vessel. Unmanned vessels are equipped with Remote Control (RC) degrees 1 to 3, where the operator is located in an SCC. To characterize a fully unmanned vessel, the ship must sail without any crewmembers, regardless of their function onboard (Bureau Veritas, 2019).

6.1 Building Blocks

The Building Blocks, as mentioned in section 1.4.4 Building Blocks Framework², are actors and factors that can form a barrier to the large-scale diffusion of an innovative product. To achieve diffusion, all 7 building blocks must be present and compatible with each other. Conversely, when not present, these building blocks form a barrier to technological diffusion (Ortt & Kamp, 2021). The sub-sections below evaluate the presence and compatibility of MASS Building Blocks.

6.1.1 Quality & Performance

The quality and performance of an innovative product are often based on the current offers in the market. The new technology has to offer sufficient performance and quality or be able to offer it shortly to be considered viable by customers (Ortt & Kamp, 2021). The requirements depend on the technology offered and MASS quality is measured based on its performance requirements. According to interviewees, voyage efficiency, particularly the use of fuel, CO2 and NOx emissions, predictability and reliability are performance indicators for maritime equipment (Interviewee 03, 2021) (Interviewee 07, 2021) (Interviewee 09, 2021) (Interviewee 08, 2021) (Interviewee 12, 2021) (Interviewee 13, 2021). In addition, the fact that an autonomous system neither gets tired nor expects unrealistic immediate response after giving a command is a valuable advantage to navigational performance. Improved navigational performance can also contribute to safety on board (Interviewee 06, 2021) (Interviewee 10, 2021), a factor that will be further discussed later in this chapter.

MASS vendors claim the technology increases voyage efficiency by making use of current streams and sailing at the ideal distance from the river margin (Interviewee 05, 2021). The technology also makes use of historical data to analyse the best route for each type of vessel and ensures fuel reduction by sailing at a constant speed (Interviewee 02, 2021). Despite not statistically proven it yet, Shipping Technology has collected data that shows not only fuel reduction but also emissions drop (Interviewee 05, 2021). Considering the new regulations mandating a sharp decrease in CO2 emissions level explained in section 3.4.2 IMO Greenhouse Gas Strategy, this aspect adds value to MASS adoption.

Despite the upcoming rule change in emissions, the environmental friendliness aspect of the MASS performance was mainly brought up by researchers and considered to be slightly important. In their opinion, the sustainability improvement offered by MASS was minimum if compared to the elimination of diesel engines, for example (Interviewee 08, 2021) (Interviewee 09, 2021). MASS adoption will become easier if vessels no longer use diesel engines as the main propulsion system, but MASS is not sufficient to achieve the mandatory 40% emission reduction required by IMO (Interviewee 08, 2021).

Considering the incapability of MASS to reduce emissions significantly to comply with the new IMO regulations, reliability, efficiency, and predictability were taken as the performance aspects that affect MASS diffusion. These performance measures were rated, on average, as very important by the interviewees that considered it a factor affecting diffusion (Interviewee 03, 2021) (Interviewee 12, 2021) (Interviewee 07, 2021) (Interviewee 13, 2021) (Interviewee 06, 2021) (Interviewee 10, 2021).

Regarding the presence of quality and performance as a building block affecting MASS diffusion, the majority of interviewees judged it as partially present.

Quality & Performance	
Partially Present	Very Important

6.1.2 Price

The price of radically new technology involves the costs to acquire it, switching costs and transaction costs among others. Ortt & Kamp (2021) propose that the price of the product influences its large-scale diffusion. According to the interviewees, however, the price is not a crucial aspect of MASS, in the maritime industry, the financial return associated with the equipment purchase (Cost-benefit) is more important than the price paid for it. The cost-benefit for MASS is calculated in terms of return on investments (ROI) (Interviewee 11, 2021), crew reduction (Interviewee 13, 2021) (Interviewee 08, 2021), fuel savings (Interviewee 07, 2021) and increased space for cargo (Interviewee 10, 2021) (Interviewee 12, 2021).

Fitting a connectivity platform and linking it to the cloud in a new-build vessel ranges from €10,000 to €100,000 depending on the number of data points. In a vessel that costs €12 to €15 million, it is not an extremely high investment. For the complete autonomy functionality, the cost would then become millions of euros because it would require many other infrastructure applications, and these are not simply fitted. Without real commercial applications to compare, it is not possible to give a full indication of the price for these vessels (Interviewee 03, 2021).

Shipping companies are interested in receiving salespeople talking about autonomous vessels, the main issue lays in the cost-benefit analysis. The manager of Boomsma Shipping (Interviewee 11, 2021) states that a guaranteed ROI would be enough to adopt the technology. For many (Interviewee 09, 2021) (Interviewee 13, 2021) (Interviewee 08, 2021) (Interviewee 10, 2021) (Interviewee 03, 2021) (Interviewee 06, 2021) the financial benefit is not visible without the crew reduction, which is determined by regulation. Companies offering MASS (Interviewee 12, 2021) (Interviewee 07, 2021) (Interviewee 05, 2021) (Interviewee 02, 2021) ensure that investing in autonomy is a valid business case that reduces costs even without crew reduction. Sea Machines sales department works with each customer to build an ROI plan that suits the purchaser, but investors have difficulties in understanding MASS ROI (Interviewee 13, 2021).

The majority of the interviewees considered the cost-benefit aspect extremely or very important, including the technology providers. An exception, however, is the Royal Dutch Navy (Interviewee 14, 2021). The Dutch Navy is less interested in ROI than it is in crew reduction. Despite the clear relationship between crew and cost reduction, the focus of the Navy is solely on crew reduction and it is related to safety and shortage of personnel, further discussed in sections 6.1.8 Safety and 6.2.3 Natural, human, and financial resources. Because of this different focus, the Royal Dutch Navy was the only actor considering Cost-benefit as slightly important.

Regarding the presence of the cost-benefit building block, most interviewees considered it absent, concluding that although extremely important to the diffusion of MASS, this factor is a large barrier to the adoption of the technology. The shipping companies cannot see the benefit of MASS adoption if the regulation does not allow crew reduction, and most are not willing to risk financial losses.

Cost-Benefit	
Absent	Extremely Important

6.1.3 Production System

A production system concerns the capacity of delivering large quantities of a product at the desired quality (Ortt & Kamp, 2021). One of the MASS researchers explained that ships are not built like cars, with a weekly production of thousands of items. Because of that, the production system for MASS cannot be expected to reach mass production. Within the scale that suits the maritime industry, the production system is still building single items, not characterised as a standard product yet (Interviewee 08, 2021).

Shipping Technology Senior Business manager agrees that there are no standards to MASS hardware and software. In his view, the production system needs certification and legislation on MASS hardware to ensure the correct standards are used (Interviewee 07, 2021). However, Sea Machines sells ready products (Interviewee 12, 2021), showing that the production of MASS, either hardware or software is already present, despite the lack of standards. Therefore, this building block was considered moderately important because many technologies face a standard battle until a standard is set in the industry (Papachristos & van de Kaa, 2020).

Production System	
Present	Moderately Important

6.1.4 Complementary Products or Services

Complementary products and services are those that support or enhance the value of another good (Schilling, 2017). Their presence also supports the production, adoption, distribution and use of the innovative product (Ortt & Kamp, 2021). For MASS, reliable satellite internet, a standard for data transfer and differentiated insurance policies add value to the technology at any autonomy level (Interviewee 10, 2021) (Interviewee 14, 2021) (Interviewee 03, 2021).

For unmanned vessels, a suitable port infrastructure will also boost adoption (Interviewee 06, 2021) (Interviewee 04, 2021). However, not all interviewees agree that complementary products are a building block for MASS. They argue that their presence is unimportant (Interviewee 08, 2021) (Interviewee 09, 2021), or that they will follow after adoption, not being necessarily irrelevant, but certainly not critical for the adoption and diffusion (Interviewee 14, 2021).

Reliable satellite internet might not be essential, as most systems operate locally and only transfer data to SCC at determined intervals (Interviewee 12, 2021) (Interviewee 05, 2021). A standard for data transfer will increase the speed of data processing and increase control in the SCCs (Interviewee 14, 2021). It is clear that these aspects improve efficiency at the SCC, but on their own, they would not be enough to affect the adoption of the technology.

Nevertheless, particular attention should be drawn to the role of differentiated insurance policies in the adoption of MASS. Among the other mentioned complementary services, insurance companies have the unique capability of influencing the cost-benefit of MASS adoption by offering reduced insurance policies for ships equipped with enhanced decision-making, also known as autonomous vessels (Interviewee 03, 2021).

Differentiated insurance policies, in the form of a complementary service, do not affect MASS diffusion alone but influence a building block that is paramount for the adoption and subsequent diffusion of MASS, the cost-benefit. Data Transfer Standard and 100% internet coverage can improve the technical performance, but not enough to stimulate adoption. Consequently, complementary products and services do not stand in as a Building Block for MASS, but as an influencing factor because its impact on the cost-benefit can be a dealmaker to return on investment pursued by shipowners.

Complementary Products & Services		
●	Absent	Hampering Factor

6.1.5 Network formation and Coordination

Network actors are companies that can supply parts, distribute, assemble, and provide complementary services (Ortt & Kamp, 2021). When customers evaluate the value of a technology, they consider the perceived value of having a network that can or will increase the product value in the future (Schilling, 2017).

There is little collaboration among MASS providers and the network of complementary services. Many companies are developing the same idea and they could all benefit from sharing experiences or offering additional services to a solution offered by another company. However, large companies developing MASS keep a closed loop of complementary services to their own developed technologies, making it very expensive for the smaller companies to offer a good cost-recovery model to the customers (Interviewee 07, 2021).

Wärtsila, for example, offers complete systems integration with its Fleet Operation Solution, combining voyage planning, voyage monitoring and smart docking assistance with weather and met-ocean data (Wärtsilä, 2021). The company uses the tests performed with the IntelliTug, mentioned in section 4.2.2 IntelliTug Projectto show the benefits of seamless integration fully offered by Wärtsilä.

Interviewees recognised Network formation and coordination as a valid building block to the diffusion of MASS and agreed that it is partially present. Notwithstanding, its importance was not highlighted, being considered slightly important to MASS diffusion.

Network formation & Coordination	
Partially Present	Slightly Important

6.1.6 Customers

The customers are an important part of any product adoption and without them, there is no diffusion. They should not only be aware of the product but also be willing to purchase it and use it (Ortt & Kamp, 2021). MASS customers are the shipowners, companies such as Boomsma Shipping, for example. Boomsma senior manager defined himself as someone that knows what autonomous shipping is, but not exactly how the technology works and how it would affect the company. In an industry where different flag states demand distinct standards from their vessels, as explained in section 3.4 Internal Context, the competition is fierce, and the profit margin is low. Only the guarantee of ROI or interest from the final customers would tip the balance to adopt MASS (Interviewee 11, 2021).

While there is the expectation that final customers will start demanding more from their transporters (Interviewee 1, 2021), this is not yet a reality. Companies hiring shipping services are only interested in transporting their goods for the lowest rate possible (Interviewee 11, 2021). Among the companies offering MASS, there are different situations; while Captain AI has plenty of potential customers and no real buyers (Interviewee 02, 2021), Sea Machines declares having sold 50 systems installed them in 30 vessels until the date of the interview, mainly to be used in survey vessels (Interviewee 12, 2021). Shipping technology uses a different strategy, the company sells a product that gives shipowners immediate insight into their performance, which will be upgraded in phases until autonomy level 4 in the future (Interviewee 07, 2021).

Undoubtfully, customers are paramount for the diffusion of MASS and some customers are willing to try the new systems in very specific operations such as survey vessels. Damen shipyards mentioned a large interest in the technology, but not actual purchases (Interviewee 03, 2021). Hence, this building block is extremely important, but not yet fully present in the MASS TIS.

Customers	
Partially Present	Extremely Important

6.1.7 Innovation Specific Institutions

Formal rules, government policies, laws and regulations are innovation specific institutions required for TIS formation. The lack of rules can block the TIS formation, consequently blocking diffusion (Ortt & Kamp, 2021). As mentioned in section 1.5.5 Regulations, the STCW has kept operations effective and safe for the past decades, but it might no longer be relevant given the level of automation currently present in ships and the autonomy proposed by MASS (Kim & Mallam, 2020).

All interviewees, except for one, considered regulations as a current barrier for MASS adoption for different reasons. Companies offering MASS and researchers agree that the lack of regulation brings uncertainty on whether MASS is good enough to be accepted by the IMO. This uncertainty reduces the value of MASS Cost-benefit and sheds doubts on the future crew reduction allowance for vessels equipped with MASS (Interviewee 08, 2021) (Interviewee 14, 2021) (Interviewee 03, 2021) (Interviewee 07, 2021) (Interviewee 12, 2021) (Interviewee 09, 2021). However, as mentioned in section 1.5.5 Regulations, the MSM is defined and controlled by the flag state (IMO, 2011), which opens the possibility of crew reduction negotiations on a national scale, instead of a global scale (Interviewee 11, 2021).

For military operations, however, regulations are not a problem. Naval ships are not obligated to fulfil IMO regulations because the military authorities governing the Navy are hierarchically above the IMO committee. Despite its lack of obligation, the Dutch Navy tries to ensure all vessels comply with international regulations, where possible. However, the use of new technologies not yet certified by the IMO is not a barrier to naval vessels, which are known to be the testbed for maritime technology (Interviewee 14, 2021).

The crew members interviewed (Interviewee 13, 2021) (Interviewee 10, 2021) (Interviewee 06, 2021) share the point of view of Klein (2020) also explained in section 1.5.5 Regulations, who considers the level of autonomy an important aspect of the legislation concerning MASS. As long as the vessel is still manned, there will be someone on board not only legally responsible for safeguarding the vessel and the crew but also liable for possible accidents. Currently, there are no conventions stating responsibilities for unmanned vessels (Mast, Pigmans, Verbeek, van 't Wout, & van Zuijdam, 2018) posing a barrier for unmanned MASS.

The Institutional aspect was deemed extremely important by interviewees and considered to be partially present, given the various national projects encouraging MASS: SMASH, ShippingLab, AUTOSHIP and ONE SEA mentioned in section 1.5 MASS Literature Review and the power of the flag state to regulate MSM, explained in section 1.5.5 Regulations.

Innovation Specific Institutions		
●	Partially Present	Extremely Important

6.1.8 Safety

6.1.8.1 – Accident Reduction

Safety is the main concern of the maritime industry. As mentioned in section 1.5.2 Safety, many researchers agreed on the need for safety for MASS, but they cannot agree if the technology will make vessels safer (Komianos, 2018) (Nautilus Federation, 2018) (Rødseth J. Ø., 2017) (Wróbel, Montewka, & Kujala, 2017). Safety is a preconditional item and it can only be increased. Every change on a vessel must increase safety, otherwise, it is not acceptable (Interviewee 03, 2021).

MASS solutions vendors use accident reduction as a selling point. Sea Machines proposes MASS for “Dull, Dangerous and Dirty” jobs because it improves safety (Interviewee 12, 2021), a point of view that is shared by Damen Shipyard project Manager (Interviewee 03, 2021). Both captains agree that machines are better at keeping stable courses and maintaining focus on long and uninteresting navigation tasks (Interviewee 06, 2021) (Interviewee 10, 2021). The shipping technology business manager also mentions that while the computer takes over the simple tasks, the captain can fulfil other duties (Interviewee 07, 2021).

Overall, the interviewees perspective is that MASS has the potential to reduce accidents and it is a driver to MASS adoption, but it is not yet fully proven and operational (Interviewee 10, 2021) (Interviewee 09, 2021) (Interviewee 13, 2021). For the Dutch Navy, safety has a different perspective, given the nature of work from naval vessels, the fewer crewmembers, the safer they are. Hence, for military applications, reduction of crew members also means increased safety (Interviewee 14, 2021). Combining all perspectives, safety can be defined as a partially present building block. Concerning its importance, there is no doubt that safety is extremely important for the adoption of any maritime technology, including MASS.

6.1.8.2 Cyber Security

This factor, previously discussed in section 1.5.3 Cyber Security was also mentioned by the interviewees. One of the interviewees mentioned the cybersecurity itself is not an issue, but the fear of it is a barrier for MASS (Interviewee 08, 2021). Others have shown real concern about the possible hacking of the vessels, using them as terrorist weapons (Interviewee 06, 2021) or robbing the cargo (Interviewee 10, 2021). Captain AI manager states that every connected device can be hacked and that the only way to overcome that is constant work on higher security levels. According to him, this is achieved with the security updates provided by MASS Sellers (Interviewee 02, 2021). This perspective shows that cybersecurity for MASS is not more neither less important than the cybersecurity of every equipment remotely controlled and connected to the Internet.

Safety		
●	Partially Present	Extremely Important

6.1.9 Overview of MASS Building Blocks

From sections 6.1.1 Quality & Performanceuntil 6.1.7 Innovation Specific Institutionsthe Building Blocks proposed by Ort and Kemp (2021) were analysed within the MASS perspective. The focus of the analysis was to validate the BBF to the specific case of MASS. In this evaluation, it became clear that most of the building blocks are important for MASS diffusion. However, small modifications had to be made to ensure complete suitability to MASS.

In section 6.1.2 Price, the building block did not suit the character of the maritime industry, where the Cost-benefit is more important than the price itself. This term was changed to Cost-benefit to ensure the framework suitability to MASS. In section 6.1.4 Complementary Products or Services, the building block is not important enough to affect MASS diffusion but serves as an influencing factor to the Cost-Benefit building block, therefore, it was removed from the Building Blocks list and added to the Influencing to Table 12 - MASS Influencing Factors. Finally, in section 6.1.8 Safety a new Building Block was added, given its extreme importance for MASS applications and all technologies applied in the maritime industry. The presence of MASS building blocks, as well as their importance, are listed in Table 11 – MASS Building Blocks

● Present ● Partially Present ● Absent

MASS Building Blocks

Quality & Performance	Very Important	● Partially Present
Cost-Benefit	Extremely Important	● Absent
Production System	Moderately Important	● Present
Network formation & Coordination	Slightly Important	● Partially Present
Customers	Extremely Important	● Partially Present
Innovation Specific Institutions	Extremely Important	● Partially Present
Safety	Extremely Important	● Partially Present

Table 11 – MASS Building Blocks

6.2 Influencing Factors

The influencing factors, as mentioned in section 1.4.4 Building Blocks Framework[2], are underlying causes for the incompletion of the Building Blocks, identifying the influencing factors helps to formulate strategies to overcome the barriers caused by absent or incomplete Building Blocks (Ortt & Kamp, 2021). The influencing factors presence, however, has a different effect than the building blocks presence. While the complete presence of a building block is a positive sign for the adoption and diffusion of breakthrough technology, the opposite is valid for influencing factors.

The presence of influencing factors shows the root cause for one or many incomplete building blocks. Therefore, differently than the previous section, influencing factors are assessed in their impact as barrier, partial barrier or encouraging factor. The sub-sections below evaluate the presence of BBF Influencing factors, which are fully explained in Table 3- TIS Influencing Factors within MASS TIS.

6.2.1 Knowledge and awareness of technology

This factor refers to the knowledge and awareness about the fundamental principles of the technology, required to produce, use, maintain, and improve the technological components. This influencing factor mainly relates to the product, production system and complementary product building blocks (Ortt & Kamp, 2021).

As a technology that is not yet fully proven, knowledge about MASS technological principles is not yet fully mastered. Some operational aspects of MASS, such as the application of COLEREGS rules, are not yet grasped by the AI systems (Interviewee 02, 2021) (Interviewee 05, 2021). Communication difficulty between vessels and harbours, or between conventional vessels and autonomous vessels was also pointed by many interviewees as a difficult operational aspect to be solved (Interviewee 06, 2021) (Interviewee 10, 2021) (Interviewee 04, 2021) (Interviewee 11, 2021).

In a more technical remark, the occurrence of solar scintillation was highlighted as a factor that can influence MASS reliability and predictability (Interviewee 10, 2021). Solar Scintillation, in a very summarized explanation, is a phenomenon caused by irregularities in the solar activity that are associated with the solar wind. These still unpredictable irregularities affect the performance of satellite positioning systems and communication, causing signal fluctuation and fading, as well as communication degradation (Xu & Song, 2019). This phenomenon would have large influences in a system based on satellite position and communication, as MASS (Interviewee 10, 2021). For autonomy levels until A2, neither COLREGs following, nor scintillation pose a problem, as the operator can correct possible AI mistakes. But it is an important influencing factor for autonomy levels A3 and A4 when the system no longer expects human confirmation.

The lack of deep understanding of MASS technological principles, which was briefly explained in section 3.2.1 Technological Principle, is also a barrier to the regulators, who do not know enough about the advantages of disadvantages of the technology to regulate its use (Interviewee 09, 2021) (Interviewee 12, 2021). Although plenty of knowledge is available from the application in aeroplanes (Interviewee 11, 2021) (Interviewee 06, 2021), many actors in the maritime industry still need to learn about MASS principles (Interviewee 02, 2021). This influencing factor is, then, partially hampering MASS adoption in the current MASS TIS.

Knowledge and awareness of technology
● Partial Barrier

6.2.2 Knowledge and awareness of application and market

Knowledge and awareness of application and market refer to how innovation can be applied in the market, including the market structure and the relevant actors in the industry. This influencing factor is mostly related to the customers building block (Ortt & Kamp, 2021). Knowledge about the MASS application is a critical aspect because even in the literature there are still misunderstandings about the difference between an autonomous and an unmanned vessel (Interviewee 02, 2021). Because of this reoccurring misunderstanding, many seafarers are afraid of being replaced by a machine (Interviewee 13, 2021).

Shipowners are also not aware of how MASS can contribute to their operations. Most of the news about autonomous vessels are about unmanned autonomous projects, as the Yara Birkeland, which are unachievable for most shipping companies in terms of investment (Interviewee 11, 2021) (Interviewee 07, 2021). Technology developers and researchers also lack knowledge about the maritime industry, disregarding the peculiarities of the industry such the entrepreneurial thinking and the seafarers (Interviewee 07, 2021). On the positive side, it is clear that knowledge about application and market has increased in recent years (Interviewee 14, 2021) (Interviewee 03, 2021). This influencing factor is, therefore, considered a partial barrier

Knowledge and awareness of application and market
● Partial Barrier

6.2.3 Natural, human, and financial resources

The lack of natural, human, and financial resources influences the development and diffusion of innovative technology. Limited natural resources can affect raw material supply and, consequently production. People with enough knowledge and competencies also need to be available to launch an innovative product. Finally, financial resources are necessary to hire knowledgeable people and buy the supplies necessary, as well as invest in further development of the product (Ortt & Kamp, 2021).

Captain AI and Shipping Technology mentioned not enough resources to innovate (Interviewee 02, 2021) (Interviewee 07, 2021). Despite the investment programs for research funded by the European Union, the investments do not fulfil their companies' needs. The research funded by the European Union does not fit the needs of the companies developing MASS solutions, neither deliver usable solutions to the market (Interviewee 07, 2021). From the perspective of the shipowners, visualising a clear Cost-benefit is still difficult without the guarantee of crew reduction (Interviewee 02, 2021), and without this clear financial benefit, most companies don't want to have MASS only to increase safety (Interviewee 13, 2021). In this context, the problem seems to be the allocation of resources, rather than its availability.

Education of seafarers was also mentioned as a necessary aspect to MASS operation (Interviewee 06, 2021) (Interviewee 13, 2021). The maritime schools follow IMO guidelines regarding the curriculum and as IMO has not yet certified this technology, learning how to work with MASS is not yet in the curriculum. This aspect does not have a large influence because currently, seafarers from many countries learn more onboard than at school (Interviewee 06, 2021). Therefore, they could also learn these technologies on board. In addition, professional courses can be offered to increase the knowledge of officers after their graduation, as it is currently done with Dynamic Positioning Officers (Interviewee 06, 2021).

As mentioned in section 3.4.1 Crew Shortage, the lack of human resources is an encouraging factor for the development of MASS (Interviewee 02, 2021) and its adoption (Interviewee 07, 2021) (Interviewee 14, 2021) for different reasons. For the commercial vessels, it is a possibility to enhance their profit margin, for the Navy, it is a solution to maintain the vessels operational even when there is little public interest in working for the military (Interviewee 14, 2021).

None of the interviewees mentioned natural resources as an influencing factor. The shortage of human resources has a positive influence on the adoption of MASS, especially for the Navy, which is not focused on profitability. The research programs investing in MASS show that financial resources are available, despite the lack of resources mentioned by Captain AI and Shipping technology. As resources are available and the lack of seafarers influences positively the adoption of MASS, this influencing factor is judged an encouraging factor in MASS TIS.

Natural, human, and financial resources
● Encouraging Factor

6.2.4 Competition

New technologies compete with other suppliers of new technology, as well as with the established technologies available in the market. Competition can influence the price, performance, production systems and complementary products and services building blocks. (Ortt & Kamp, 2021). Not many companies are working on MASS solutions (Interviewee 09, 2021) and very few can offer complete integration of maritime equipment and autonomy (Interviewee 13, 2021). This could be one of the reasons companies offering MASS solutions do not experience competition among themselves (Interviewee 12, 2021) (Interviewee 07, 2021), but with the status quo, the conventional ships (Interviewee 02, 2021). Given the lack of companies offering MASS, the market cannot profit from a decrease in prices and an increase in quality (Interviewee 03, 2021).

On the one hand, MASS can also influence a modal shift, replacing the trucks. On the other hand, it can be fully replaced by trucks if their technological development is faster. MASS can make barge transport cheaper and more efficient, saving fuel costs and reducing waiting time, competing with truck transport. The current focus on CO2 emissions focus is challenging truck transportation, creating an ideal window to make this modal shift to barges. When trucks become electrics, and later autonomous, barges will most likely just disappear (Interviewee 02, 2021).

Even though more than one company offers a MASS solution to the market, the competition is still too small to have a positive influence on the price and quality. Consequently, MASS is still not able to compete on equal terms with the status quo, either in the form of conventional vessels or in a modal shift, which deems the competition a partial hampering factor.

Competition
Partial Barrier

6.2.5 Macroeconomic and strategic aspects

The macro-economic aspect of a country involves market conditions and current economic policies, both influence the strategic direction of the companies (Ortt & Kamp, 2021). The maritime industry is currently at the bottom of its ordering cycle, and it will go up in the coming 10 years (Interviewee 1, 2021), which means more ships are expected to be ordered and built in the coming future. The decision of which technology to add in a new-build ship considers that the ship should be operational for the next 20 years with the minimum modifications possible (Interviewee 03, 2021).

The lack of regulations about MASS increases the financial risk of investment for shipowners (Interviewee 11, 2021), which is an important aspect of the low-profit-margin risk-averse maritime industry (Interviewee 02, 2021). For the military vessels, the macroeconomic situation is translated into budget allocation for technological developments, also affecting their strategic plans. But different from the commercial vessels, the Dutch Navy has more flexibility regarding national and international regulations and is not pressured by profit margin (Interviewee 14, 2021). Therefore, the macroeconomic and strategic aspects are encouraging for the military vessels and the commercial vessels. The difference is the level of risk each niche of the maritime sector needs to accept to design a strategy that suits the current macroeconomic scenario.

Macroeconomic and strategic aspects
Encouraging factor

6.2.6 Socio-cultural aspects

Socio-cultural aspects are defined by the values and norms held by potential customers. Despite not having the same power of laws and regulations, it can impact the TIS in both positive and negative ways. An important characteristic of the social-cultural aspect is that it can change rather quickly if compared to formal laws and regulations (Ortt & Kamp, 2021).

The maritime industry is not known for its openness to change (Interviewee 02, 2021). It is a conservative industry with a very strict task division on board (Interviewee 09, 2021). Society at large also influences the adoption of autonomous technologies, and people want the technology to be safer than humans, a mistake from a machine that ends up in the loss of human life is unacceptable, despite its frequency (Interviewee 04, 2021).

Besides the overall fear of AI, many seafarers are concerned about their job and their safety (Interviewee 13, 2021) (Interviewee 06, 2021), a social aspect of MASS that is related to the knowledge and application of the technology that cannot be underestimated. While society at large plays a role, ultimately the crew members are paramount to MASS acceptance. The crew can influence how the system operates, consequently, if they are against it, the technology will not deliver its expected benefits (Interviewee 03, 2021). Therefore, this influencing aspect is judged as a partially hampering factor .

Socio-cultural aspects
Partial Barrier

6.2.7 Accidents and events

Natural disasters, national and international events can impact the TIS formation and affect the adoption of new technologies (Ortt & Kamp, 2021). For the maritime industry, this is certainly applicable, as many of the current international regulations were developed after tragic accidents like the sinking of the Titanic, and the oil spill caused by the Exxon Valdez (Hebbar, 2006).

The latest attention-catching event involving a ship was the Ever Given blockage of the Suez Canal for 6 days in March 2021. This event cost millions of dollars to the shipowner and a global supply chain shortage (BBC News, 2021). The cause is under investigation, but no results were published before the end of this report (Ovcina, 2021). Accidents, however, are not unusual at sea, as mentioned in section 1.5.2 Safety in the literature review, 65.8% of the accidents in the maritime industry are caused by human errors and MASS could decrease these numbers (Wärtsilä, 2021). Despite not having one accident to name, the large number of accidents can be characterized as an encouraging factor to the adoption of MASS, given one of the selling points of the technology is to reduce accidents.

Accidents and Events
● Encouraging Factor

6.2.8 Operational Aspects

The Operational aspects are not mentioned in Ortt & Kamp framework but were mentioned by many interviewees. These aspects refer to factors that influence the regular operation of autonomous vessels, such as maintenance in the propulsion engines, especially diesel engines, cargo value and inspection, communication with other vessels and port facilities and finally stormy seas (Interviewee 08, 2021) (Interviewee 13, 2021) (Interviewee 10, 2021) (Interviewee 14, 2021) (Interviewee 11, 2021) (Interviewee 06, 2021) (Interviewee 04, 2021) (Interviewee 07, 2021).

These aspects, however, are related to the unmanned operation of the vessels, because as long as the vessel is locally operated, there will be a crew on board to deal give maintenance to the engines, ensure cargo safety, communicate, and perform manoeuvres to ensure the vessel water tightness. Consequently, this factor does not currently have an immediate influence on MASS adoption, but it will have an effect later in the large scale diffusion of MASS when the control of the vessels is moved to SCCs.

Operational Aspects
● Hampering Factor

6.2.9 Influencing Factors

The sub-sections above analysed the Influencing factors proposed by Ort and Kemp (2021) applied to the MASS perspective. The focus of the analysis was to evaluate the suitability of the BBF Influencing factors to MASS as a breakthrough technology. In this analysis, all the influencing factors were found to affect MASS adoption indirectly. This means none of them can influence adoption alone, but they do influence the Building Blocks which, in turn, affect adoption and diffusion directly.

As mentioned in section 6.1.9 Overview of MASS Building Blocks, the building block explained in section 6.1.4 Complementary Products or Services did not qualify as a Building block because it acts as a barrier to the Cost-benefit building block, but it is not a "show-stopper" for MASS diffusion on its own. Therefore, this factor was added to the Influencing Factors, presented in Table 12 - MASS Influencing Factors.

Finally, not all factors affecting MASS diffusion mentioned by interviewees could be added to Ort and Kemp (2021) categories. Therefore, as explained in section 6.2.8 Operational Aspects, one more influencing factor was added to the framework. Despite not being capable of affecting adoption now, operational factors will influence large scale diffusion in a later stage of the technology adoption and need to be addressed for unmanned MASS.

MASS Influencing Factors

Knowledge and awareness of technology	Partial Barrier
Knowledge and awareness of application and market	Partial Barrier
Natural, human, and financial resources	Encouraging Factor
Competition	Partial Barrier
Macroeconomic and strategic aspects	Encouraging Factor
Socio-cultural aspects	Partial Barrier
Accidents and Events	Encouraging Factor
Complementary Products & Services	Hampering Factor
Operational Aspects	Hampering Factor

Table 12 - MASS Influencing Factors

6.3 Factors Affecting the MASS adoption

The analysis of MASS Building Blocks and Influencing factors in comparison with the Breakthrough technologies BBF proposed by Ortt & Kamp (2021) has shown that the majority of the BBF suits MASS TIS. Despite the small modifications made to the building blocks to ensure full compatibility with MASS explained in section 6.1.9 Overview of MASS Building Blocksthe essence of the framework applies to this developing technology.

All Influencing factors proposed by Ortt & Kamp (2021) were found to be important for the MASS TIS and 2 more were added to ensure the framework suits MASS completely, as mentioned in section 6.2.9 Influencing Factors. The complete overview of MASS Building Blocks and Influencing factors is summarized in Table 13- MASS Building Blocks & Influencing Factors, which answers the research sub-question “What are the actors and factors affecting the adoption of MASS?”.

MASS Influencing Factors			**MASS Building Blocks**
🟢 Encouraging Factor 🟠 Partial Barrier 🔴 Hampering Factor			🟢 Present 🟠 Partially Present 🔴 Absent
Knowledge and awareness of technology	🟠	🟠	Quality & Performance
Knowledge and awareness of application and market	🟠	🔴	Cost-Benefit
Natural, human, and financial resources	🟢	🟢	Production System
Competition	🟠	🟠	Network formation & Coordination
Macroeconomic and strategic aspects	🟢	🟠	Customers
Socio-cultural aspects	🟠	🟠	Innovation Specific Institutions
Accidents and Events	🟢	🟠	Safety
Complementary Products & Services	🔴		
Operational Aspects	🔴		

Table 13- MASS Building Blocks & Influencing Factors

7. The way to Autonomy

This chapter presents solutions to overcome the barriers to MASS diffusion presented in section 6.3 Factors Affecting the MASS adoption using the solutions proposed by the interviewees, the theory presented in section 1.4.5 Technology Introduction Strategies and a combination of both to ensure complete suitability to MASS TIS. The chapter is divided into 2 sub-sections.

In the sub-section 7.1 Overcoming Hampering factors, the solutions mentioned in the 1.5 MASS Literature Review are combined with the solutions proposed by the interviewees and the niche strategies explained in section 1.4.5 Technology Introduction Strategies. Sub-section 1 ends with a list of separate solutions that can be used by companies offering MASS to surmount the barriers to adoption and consequent diffusion . This list answers research sub-question 4 “How could actors and factors hampering autonomous ships be surmounted?”

In sub-section 2, 7.2 Pathways to MASS Diffusion, takes the approach proposed by Bergek et al. (2008) explained in section 1.4.3 Technological Innovation System (TIS), in which actors and factors present in the TIS need to be addressed as a system and not separately. Using this perspective, this section develops on the data from Table 13- MASS Building Blocks & Influencing Factors, identifying the relationships among building blocks and influencing factors. These relationships are then combined with the separate solutions proposed in section 7.1 Overcoming Hampering factors to define potential pathways to MASS diffusion, answering research sub-question 5 “What are the potential strategies to remove barriers and capitalize on encouraging factors to autonomous ships technology?”

Section Research7.2 Pathways to MASS Diffusion also presents the answer to sub-question 6 “How can these pathways be used to facilitate autonomous ships technology diffusion in other application niches?” By combining answers to sub-question 5 and the MASS applications discussed in Section 4.4 Characteristics of the current MASS applications.

7.1 Overcoming Hampering factors

7.1.1 Quality & Performance

As explained in section 6.1.1 Quality & Performance, the main issue with MASS lays in the fact that the technology is not yet proven. The promises of fuel savings reduced emissions, increased efficiency, predictability, and reliability are, for many, just a promise (Interviewee 13, 2021) (Interviewee 10, 2021). Little is known about the commercial tests, companies only share Public Relations articles, as the Yara Birkeland, which is still not yet operational (Hellenic Shipping News, 2021), despite all the positive articles during its initial tests (Kongsberg, n.d.). Most interviewees have declared not to know much about how MASS really works, the fact is that the technicalities of the technology enlighten what it is capable of and what is not.

As explained in section 3.2.1 Technological Principle, MASS is based on ANN, which is similar to a human neural network. This means that, just like humans, it needs to learn before performing a task (Russell & Norvig, 2010), and the more complex the task, the longer the training time (Kooij & Loonstijn, 2018). These details explain why it is difficult for companies offering MASS to simply prove its efficiency as if they were selling an electric bike.

Demonstrating, however, is not impossible and it was the suggestion given by crew members interviewed as a way to prove MASS can deliver what it promises (Interviewee 13, 2021) (Interviewee 10, 2021). The Demo experiment and Develop Niche strategy, mentioned in Table *4*, suggests a similar approach. In the Demo experiment and Develop Niche strategy, the technology developers demonstrate the product in a controlled environment to further develop it and learn with it at the same time it enhances awareness of the public about it Ortt, Langley, & Pals (2013).

Nevertheless, it is not possible to bring an autonomous vessel to a shopping street and demonstrate its abilities on a Saturday afternoon. MASS needs a demonstration that can be followed at a distance, similar to the blog created by the Mayflower developers (Mayflower, n.d.). Despite the failure of the Mayflower mission, it was possible to follow what the vessel was doing, showing its capabilities on daily basis in its designated blog, which enhances the trust in the system's capabilities.

That is an expensive endeavour for an unmanned vessel, as everything is automated and connected to the cloud, but for an autonomous vessel with a crew on board, some videos and technical explanations posted to the public on regular basis may increase the visibility and reliability of MASS, reducing the doubts about it and proving its quality while AI is still learning. As a by-product, such online activity might also improve the awareness of the technology and its application. To ensure that the demonstration can only take place digitally, this niche strategy is named the Digital Demo experiment and Develop Niche Strategy.

Building Block	**Solution**
Quality & Performance	Digital Demo experiment and Develop Niche Strategy.

7.1.2 Cost-Benefit

One point was very clear for most interviewees: If the companies offering MASS want the technology to be adopted, they need to make a clear business case (Interviewee 09, 2021) (Interviewee 04, 2021) (Interviewee 01, 2021) (Interviewee 08, 2021) (Interviewee 11, 2021). From the perspective of the companies offering technology, regulations must recognise MASS and allow crew reduction (Interviewee 07, 2021) (Interviewee 12, 2021) (Interviewee 02, 2021). Indeed, if the crew reduction is approved, the decision to adopt MASS becomes a no-brainer (Interviewee 11, 2021). However, Schröder-Hinrichs et al. (2013) state that IMO has a history of taking reactive measures after accidents instead of proposing new solutions using available knowledge. Therefore, waiting for an international regulation might take years and then the hype around MASS will have passed (Interviewee 09, 2021).

Ortt, Langley, & Pals (2013) present 2 strategies that can be used to overcome the Cost-benefit barrier, both described inTable *4*. The first one is the Top Niche strategy, which aims at a market that is not constrained by the price of the technology (Ortt, Langley, & Pals, 2013). As mentioned in section 6.1.2 Price, the Royal Dutch Navy is more interested in crew reduction than in cost-benefit and it does not have the obligation to comply with international rules regarding crewing, as explained in section 6.1.7 Innovation Specific Institutions. Therefore, a suitable option for the Top Niche strategy. Another maritime sector known for not having budget constraints is the Leisure yacht (Interviewee 14, 2021), which can be open to MASS adoption without cost-benefit concern.

The second one is the Hybridization Niche Strategy, which entails making the new product compatible with existing complementary services or combine the new product with the old version (Ortt, Langley, & Pals, 2013). This strategy is similar to the one being pursued by Shipping Technology and Sea Machines. Both companies offer MASS to existing vessels, Sea Machines ensures it sells a product and not a project, offering installation in every ship (Interviewee 12, 2021).

Shipping Technology focuses on retrofitting, which means installing the equipment in vessels already operating. Currently, the Shipping Technology offers cloud connectivity, giving visibility to shipowners, not autonomy. The equipment installed, however, will learn with the vessel and, in the future, the company will add autonomy to the already sold product (Interviewee 07, 2021). The approach used by the company resembles a combination of the previously mentioned Hybridization Niche Strategy with the Lead User Niche Strategy, which is explained by Ortt, Langley, & Pals, (2013) as a partnership with lead users willing to experiment with technology. The possible solutions for the Cost-benefit barrier are summarised in the block below.

Building Block	Solution
Cost-Benefit	Top Niche Strategy.
	Hybridization Niche Strategy
	Lead User Niche Strategy

7.1.3 Network formation & Coordination

There is little collaboration among MASS providers and the network of complementary services (Interviewee 07, 2021), as mentioned in section 1.4.4 Building Blocks Framework², this factor is closely related to Complementary Products and services. As discussed in section 6.1.4 Complementary Products or Services, the presence of Complementary Products and Services does not directly affect the diffusion of MASS but influences the Cost-benefit Building Block. Hence, it is possible to deduce that within MASS TIS, the network formation indirectly influences the Cost-benefit. On the other hand, it directly affects the knowledge of the technology and its application.

Among the strategies suggested by Ortt, Langley, & Pals (2013), none of them addresses the network formation Building Block, but Dasaratha (2019) mentioned in section 1.4.5 Technology Introduction Strategies, proposes a public innovator to serve as an intermediary in the network formation. In the MASS context, a technical university studying MASS technology could fulfil the public innovator role in the system. Despite not having control over what the researchers develop in the universities, companies offering MASS solutions could profit from a close relationship with academic researchers and enhance the network formation for MASS.

Building Block	Solution
Network Formation & Coordination	Relationship with institutions researching MASS

7.1.4 Customers

Without customers, there is no diffusion and to purchase, customers need to be aware of the technology and have the resources to purchase it (Ortt & Kamp, 2021). As explained in sections 6.1.6 Customers and 6.2.1 Knowledge and awareness of technology, potential customers lack awareness of MASS competencies, which affects their interest in installing the technology in their vessels. To increase customers' interest, companies offering MASS solutions need to educate their market (Interviewee 02, 2021).

Ortt, Langley, & Pals, (2013) recommend the use of the Educate Niche Strategy to ensure customers have a better understanding of the technology. The authors suggest organizing conferences and closing partnerships with universities as means to enhance the knowledge and awareness of innovative technologies. Organizing conferences can be rather costly to companies struggling for financial resources, and as was mentioned in section 6.2.3 Natural, human, and financial resources, this is the situation of most small companies offering MASS solutions.

Another option to increase technology awareness is to partner with universities in projects related to MASS or make active use of the already existing autonomous vessels programs mentioned in section 1.5.1 MASS Potential. Participation in these projects can have a twofold contribution to MASS adoption. On the one hand, smaller companies can piggyback on the resources of the national programs to enhance awareness about their product. On the other hand, as mentioned in section 1.4.5 Technology Introduction Strategies, the participation of informational intermediaries, which in this case are the universities and the joint industry projects, facilitates the network formation for MASS. Therefore, adopting the Educate Niche Strategy helps the companies solving the Customers barrier to MASS adoption and diffusion.

Building Block	**Solution**
Customers	Educate Niche Strategy

7.1.5 Innovation Specific Institutions

The institutions, more specifically the bodies regulating the number of crew members onboard, pose a large barrier to MASS adoption. As previously discussed in section 6.1.7 Innovation Specific Institutions, the uncertainty about crew reduction possibilities hampers the adoption of MASS, except for military applications (Interviewee 14, 2021). Given the already explained in sections 6.1.2 Price, 6.2.3 Natural, human, and financial resources and 7.1.2 Cost-Benefit, changes in regulations can have a substantial influence on MASS diffusion.

Ortt, Langley, & Pals, (2013) propose the Geographic Niche strategy when breakthrough technologies are restricted by regulations, suggesting introducing the technology in areas with more flexible rules. Considering the power of the flag state to determine the number of crew members in vessels flying their flag and the concept of territorial waters, explained in section 3.4.3 Maritime Laws & Regulations, companies offering MASS can request an MSM reduction with the flag state, and within territorial waters. Despite not having control of the results of these crew reduction requests, the companies offering MASS solutions stand better chances of success focusing on national entities, a solution that was also proposed by Rødseth (2017) in section 1.5.5 Regulations, than waiting for an IMO international recognition.

Building Block	Solution
Innovation Specific Institutions	Geographic Niche Strategy

7.1.6 Safety

Safety is not a building block encompassed by Ortt & Kamp (2021) framework, but it is paramount to MASS adoption, as clarified in section 6.1.8 Safety. Therefore, there is no entry strategy presented in 1.4.5 Technology Introduction Strategies. That is designed to ensure the safety of a product in its market introduction. Hence, a strategy needs to be created to ensure MASS can overcome this diffusion barrier.

In section 1.5.2 Safety, Wróbel, Montewka, & Kujala (2017) highlight the complexity of proving safety, as it is defined by the absence of accidents. In the same section, Ventikos, Chmurski, & Louzis (2020) suggests the human perspective in the autonomous ships, not on board, but as input for decisions taken by AI and helping to set up the system's safety standards. Although helpful, Ventikos, Chmurski, & Louzis suggestion does not influence MASS adoption because the input of humans in the AI making-making process is not visible to crew members and shipowners that will operate and buy the technology respectively.

As proposed by Ortt & Kamp (2021) and described in the 1.4.4 Building Blocks Framework[2], the influencing factors play a considerable role in surmounting the barriers to diffusion. In MASS TIS, safety is a building block affected by accidents and events, knowledge and awareness of the technology and socio-cultural aspects, a relationship that is further discussed in section 7.2 Pathways to MASS Diffusion, where the connection between the other building blocks and influencing factors is also described. Using the above-mentioned perspective, it is possible to infer that a strategy to overcome the safety barrier must include measures related to accidents and events, socio-cultural and awareness of the technology influencing factors.

While Ortt, Langley, & Pals, (2013) do not suggest strategies to deal with safety as a building block, the authors do indicate a strategy to enhance the knowledge and awareness of the technology, the Educate Niche strategy. This strategy, mentioned in section 7.1.4 Customers as a suitable strategy to improve the knowledge of the customers, can also be used to tackle one of the influencing factors affecting the safety building block. Given the exogenous nature of the accidents and events, and the socio-cultural factors within the MASS TIS, a strategy to address these factors goes beyond the scope of this study.

Building Block	Solution
Safety	Educate Niche Strategy

7.1.7 Strategies to Surmount MASS Barriers

Table *14* shows the status of MASS building blocks according to the colour code previously used in tablesTable *11*,Table *12*, and Table *13*, as well as the strategies to surmount each of the MASS building blocks posing a barrier to its diffusion. The only factor which is currently not posing a barrier to MASS diffusion is the production system, and for this reason, no strategy was proposed for it.

Present Partially Present Absent

Strategies to Surmount MASS Barriers		
Quality & Performance		Digital Demo experiment and Develop Niche Strategy.
Cost-Benefit		Top Niche Strategy.
		Hybridization Niche Strategy
		Lead User Niche Strategy
Production System		
Network formation & Coordination		Relationship with institutions researching MASS
Customers		Educate Niche Strategy
Innovation Specific Institutions		Geographic Niche Strategy
Safety		Educate Niche Strategy

Table 14- Strategies to Surmount MASS Barriers

The strategies presented in Table 14- Strategies to Surmount MASS Barriers shows separate ways to deal with each incomplete or absent building block in the MASS TIS. However as recommended by Bergek et al. (2008) and described in section 1.4.3 Technological Innovation System (TIS), the actors and factors within a TIS are correlated, which means solving one of them might turn the others into more problematic, or not have the desired effect. An example can be taken from the cost-benefit building block and the Top Niche Strategy mentioned above. If a company offering MASS solutions focuses only on this strategy as the path to diffusion, it has little chance of succeeding, as both the

Navy and the leisure yachts are a small percentage of the maritime industry. The strategy would be minimizing the importance of the customers, safety and Innovation institutions, all deemed to be also extremely important in MASS TIS, as shown in Table 11 – MASS Building Blocks. Since many factors are extremely important, a pathway addressing them simultaneously has a higher probability of success on the road to MASS diffusion. These pathways are explained in section 7.2 Pathways to MASS Diffusion.

7.2 Pathways to MASS Diffusion

Ort and Kemp (2021) suggest that the incompleteness or absence of the building blocks forms a barrier to technological innovation diffusion, as mentioned in section 1.4.4 Building Blocks Framework[2]. The BBF proposes analysing the influencing factors to better assess the reason for the building blocks incompleteness, which was done in section 6.2 Influencing Factors and a complete overview is presented in Table 13- MASS Building Blocks & Influencing Factors.

Combining the factors proposed by the interviewees and their explanations made it possible to highlight the relationships between the barriers mentioned and the cause for these barriers. Chapter 6. Factors Affecting MASS Diffusion explains each MASS factor affecting diffusion, underlying reasons for their importance in the MASS TIS, as well as reasons for their presence or absence as perceived by the interviewees. So far, some relationships became obviously clear, such as the mutual connection between the cost-benefit and the Institutions, while others need a better analysis to surface.

The goal of this section is to uncover less obvious relationships, presenting an overview of how the influencing factors affect the building blocks. As suggested by Bergek et al. (2008), explained in section 1.4.3 Technological Innovation System (TIS), the relationships within the TIS affect the technology diffusion. Thus, to ensure the MASS pathway to diffusion is properly built, it is important to highlight the not-so-obvious relationships among the factors affecting the MASS TIS, as well as the importance of the influencing factors in the TIS, both perspectives are shown in Tables Table 15 - Relationships between Building Blocks & Influencing Factors and Table 16- Influencing Factors Importance Rank.

7.2.1 Relationships between MASS TIS factors

Present Partially Present Absent

Building Blocks		Related Influencing Factors
Quality/ performance	X	Knowledge and awareness of technology
	X	Knowledge and awareness of application and market
	X	Natural, human, and financial resources
	X	Competition
	X	Macroeconomic and strategic aspects
	X	Socio-cultural aspects
	X	Accidents & Events
		Complementary Products & Services
		Operational Aspects
Cost-Benefit	X	Knowledge and awareness of technology
	X	Knowledge and awareness of application and market
	x	Natural, human, and financial resources
	X	Competition
	X	Macroeconomic and strategic aspects
	X	Socio-cultural aspects
		Accidents & Events
	X	Complementary Products & Services
		Operational Aspects
Production System		Knowledge and awareness of technology
		Knowledge and awareness of application and market
	X	Natural, human, and financial resources
		Competition
		Macroeconomic and strategic aspects
		Socio-cultural aspects
		Accidents & Events

	X	Complementary Products & Services
		Operational Aspects
Network formation & Coordination	X	Knowledge and awareness of technology
	X	Knowledge and awareness of application and market
	X	Natural, human, and financial resources
		Competition
	X	Macroeconomic and strategic aspects
	X	Socio-cultural aspects
		Accidents & Events
		Complementary Products & Services
		Operational Aspects
Customers	X	Knowledge and awareness of technology
	X	Knowledge and awareness of application and market
	X	Natural, human, and financial resources
		Competition
	X	Macroeconomic and strategic aspects
	X	Socio-cultural aspects
	X	Accidents & Events
		Complementary Products & Services
		Operational Aspects
Innovation Specific Institutions	X	Knowledge and awareness of technology
	X	Knowledge and awareness of application and market
	X	Natural, human, and financial resources
		Competition
	X	Macroeconomic and strategic aspects
	X	Socio-cultural aspects
	X	Accidents & Events
		Complementary Products & Services
		Operational Aspects

	X	Knowledge and awareness of technology
		Knowledge and awareness of application and market
		Natural, human, and financial resources
		Competition
Safety		Macroeconomic and strategic aspects
	X	Socio-cultural aspects
	X	Accidents & Events
		Complementary Products & Services
		Operational Aspects

Table 15 - Relationships between Building Blocks & Influencing Factors

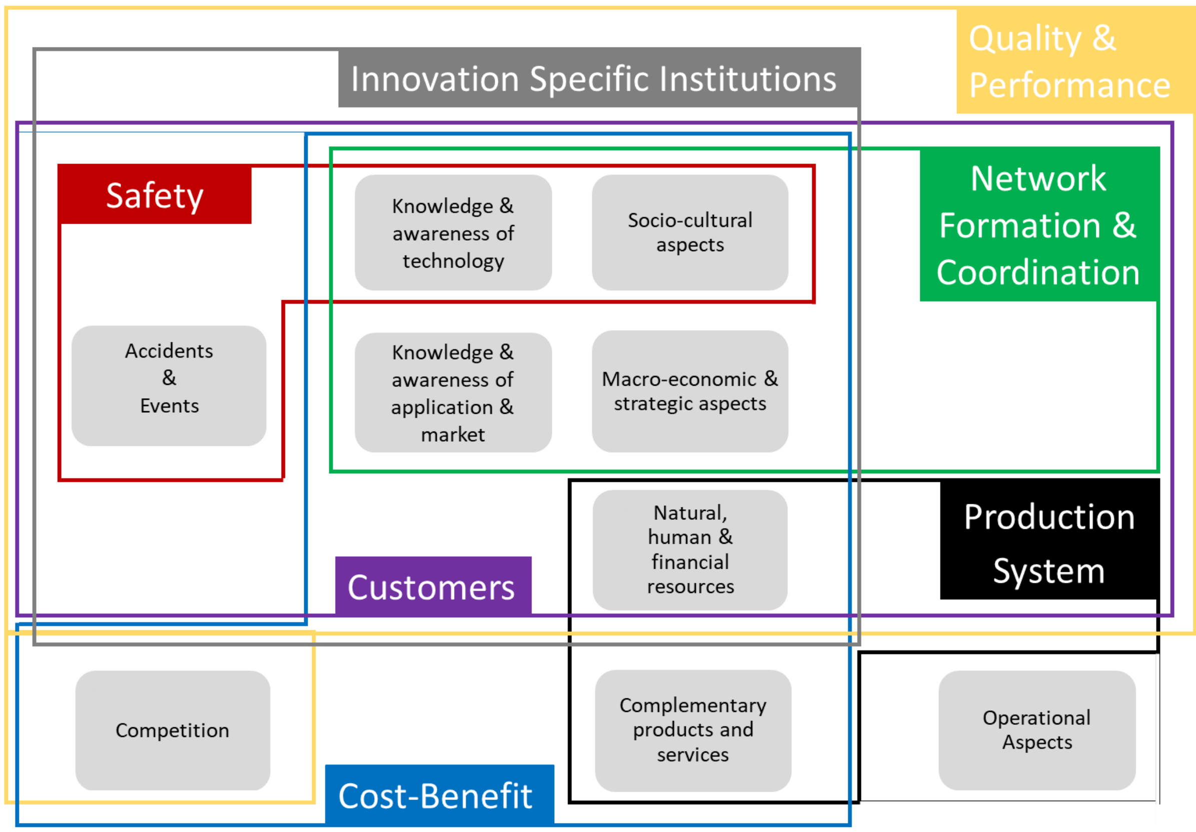

Figure 27- Relationships between building blocks & Influencing Factors

The relationships depicted in Figure *27* and Table *15* with the details about each building block and influencing factors explained in section 6.2 Influencing Factors tells the story about MASS TIS. In the following piece of text, **BUILDING BLOCKS** will be written in bold capital letters and **influencing factors** will be depicted in bold lowercase to highlight their presence in the story.

The MASS TIS story

The story starts with the **COST-BENEFIT** because the shipowners, hereinafter **CUSTOMERS,** are interested in increasing their profit margin or reducing their costs and MASS **COST-BENEFIT** is guaranteed with crew reduction, which is a **natural, human & financial resource.** Seafarers' shortage is another reason for crew reduction but depends on either national or international **INNOVATION SPECIFIC INSTITUTIONS.** They regulate the number of crew members on board, but **INNOVATION SPECIFIC INSTITUTIONS** also need to ensure the technology fulfils **SAFETY** standards.

MASS **QUALITY & PERFORMANCE** has accident reduction as number 1 priority, therefore, **SAFETY** improvement. But proving **SAFETY** is rather complex, MASS needs to be used to prove its potential**.** A large **accident or event** in the recent past would highlight the need for more **SAFETY** in the industry, but small accidents do not come on regular news. Therefore, the huge number of maritime accidents in the past years did not affect the **socio-cultural** perspective of **SAFETY** in the maritime industry and did not trigger the **INNOVATION SPECIFIC INSTITUTIONS** to act upon this problem.

Without the **knowledge & awareness of the technology,** it is complex to understand MASS **QUALITY & PERFORMANCE** and how it can increase **SAFETY**, which makes the **CUSTOMERS** and **INNOVATION SPECIFIC INSTITUTIONS** reluctant to simply accept the word of MASS sales personnel. In fact, **knowledge & awareness of the technology** and **knowledge & awareness of application & market** lack for many actors in MASS TIS and that affects the **NETWORK FORMATION & COORDINATION.**

The **NETWORK FORMATION & COORDINATION** can increase **knowledge & awareness of the technology and knowledge & awareness of application & market,** stimulating **competition**, which will finally improve **QUALITY & PERFORMANCE** and ensure a better **COST-BENEFIT.** The larger the **NETWORK FORMATION & COORDINATION,** the bigger the availability of **Complementary Services,** which also positively affect the **COST-BENEFIT** and the **PRODUCTION SYSTEM** OF MASS.

On the positive side, the **CUSTOMERS** know that the current **macro-economic and strategic aspects** of the industry look positive, the shipping business is expected to grow soon. Lack of regulation by the **INNOVATION SPECIFIC INSTITUTIONS** surfaces the well-known **socio-cultural aspect** of the maritime industry, the resistance to change and the conservative way of looking to business. From the International **INNOVATION SPECIFIC INSTITUTIONS** side, there is more than **SAFETY** at stake, crew reductions may cause job losses, which will affect the **macro-economic and strategic perspective** of many countries that are part of the International **INNOVATION SPECIFIC INSTITUTIONS…**

MASS TIS is an endless story and if no changes occur, it will never reach diffusion (Interviewee 09, 2021). The TIS is full of interdependencies, validating Bergek et al. model (2008). For MASS most influencing factors are incomplete, or even if they are present, they relate to building blocks that depend on influencing factors currently acting as barriers. While the story puts the relationship Figure *27* and Table *15* in words, it does not show the importance of the influencing factors.

To complete the overview, Table *16* shows the importance of influencing factors in the MASS TIS. The factors were ranked based on how many building blocks they affect, considering the importance of the influencing factor as is directly proportional to the number of building blocks affected by it. The ranking shows that socio-cultural aspects are as important as knowledge and awareness of the technology for MASS diffusion, an underlying relationship that was not immediately noticeable in the separate analysis of the influencing factors in chapter 6.

Influencing Factor	**Importance Rank**
Knowledge and awareness of technology	1st
Socio-cultural aspects	
Natural, human, and financial resources	
Knowledge and awareness of application and market	2nd
Macroeconomic and strategic aspects	
Accidents & Events	3rd
Competition	4th
Complementary Products & Services	
Operational Aspects	5th

Table 16- Influencing Factors Importance Rank

The Complementary Product and service, as well as the Operational aspects, are the ones with the least influence in the building blocks, which leads to 2 conclusions: The first one is the validity of the BFF to assess MASS, as the factors proposed by Ort and Kemp (2021) are entirely valid and more important than the added influencing factors aggregated to fit MASS TIS. The second conclusion is the confirmation that MASS is a technology currently in the adaptation phase, as explained in chapter 5. MASS Pattern of Diffusion

This confirmation comes from the fact that the 2 added influencing factors, complementary products, and services, as well as operational factors, are the least important factors in the current MASS TIS. As explained in sections 6.1.4 Complementary Products or Services and 6.2.8 Operational Aspects, both factors have little influence on the adoption of the technology but they will increase in importance when adoption increases and MASS start heading to the large-scale diffusion phase.

7.2.2 Pathway Stepwise Approach

The development of the pathway starts with understanding the TIS of the technology, which in this research is MASS and it was presented in Chapter 3. It is followed by the use of the BBF to better understand the impact of each building block in the TIS, which starts to reveal the relationships between the building blocks and the influencing factors, in this study, this step is shown in chapter 6.

In the specific case of MASS, it was not yet known in which pre-diffusion phase, therefore the PDM was used to determine the pre-diffusion phase in chapter 5. However, if the pre-diffusion phase of the technology is already determined, this step can be removed. The fourth step is to select strategies to overcome the diffusion barriers presented by the BFF and the TIS analysis. These strategies depend on the pre-diffusion phase of the technology, hence, determining the pre-diffusion phase allows the selection of strategies that suit the correct phase of technological diffusion. For MASS, which is currently in the adaptation pre-diffusion phase, technology introduction niche strategies, explained in section 1.4.5 Technology Introduction Strategies, designed for this phase were used as a guideline.

The fifth step is to evaluate the relationship between the building blocks and the influencing factors, determining which influencing factors affect each building block, determining the importance of the influencing factors based on the number of building blocks they affect, as well as the importance of the building blocks. In this report, this evaluation was done in section 6.1 Building Blocksfor the building blocks importance and in section 7.2.1 for the importance and the influencing factors and their relationship with the building blocks. This approach allows not only understanding of the interconnectivity, but also the recognition of the most important building blocks and influencing factors in the TIS.

Finally, combine the strategies selected to overcome barriers into a logical path, taking into account the interconnectivity of the influencing factors, and the fact that they affect multiple building blocks. In this combination, it is important to ensure the most important building blocks and influencing factors are addressed first, proportionating a cascade effect, which serves as the start of the solution to the other building blocks and influencing factors. Once all the relationships are addressed, the pathway is completed.

Stepwise Approach to Pathway Development

Step	Action
1	Understand the TIS by exploring the technology itself, the internal and external environments in which it is being developed.
2	Use the BBF to determine the status and the importance of the building blocks and influencing factors in the TIS.
3	Determine the Pre-diffusion phase of the technology
4	Select strategies to overcome the TIS barriers based on the pre-diffusion phase.
5	Evaluate the relationships between the building blocks and the influencing factors, considering the importance of both aspects.
6	Combine the strategies into one pathway giving preference to address the most important building blocks and influencing factors first.

Table 17 - Stepwise approach to Pathway development

7.2.3 Institutional Pathway

The relationships detailed in section 7.2.1 show that some building blocks are fairly independent, as the production system, which is only connected to Complementary services and Natural, human, and financial resources. The fact that it is the only present building block in MASS TIS can be attributed to its simplicity, as well as to the fact that resources are fully present, and the complementary products and services affect have more effect on the large scale diffusion than on the adoption of MASS.

The other building blocks, however, have more connections with influencing factors that are not complete and affect MASS adoption. Despite the maze of relationships, the completion of the innovation specific institutions building block can have a great impact on MASS TIS. The adaptation of current regulations to MASS, allowing crew reduction for vessels equipped with autonomous capabilities would tip the balance of the TIS towards MASS adoption.

As explained in sections 3.4.3 Maritime Laws & Regulations and 6.1.7 Innovation Specific Institutions, and depicted in The MASS TIS story, the permission to reduce crew upon MASS use ensures the presence of the most important building block in the TIS, Cost-benefit. It gives the risk-averse industry the certainty the customers need to invest in MASS, ensuring fulfilment of the socio-cultural aspect. If the cost-benefit is present with the support of the maritime regulations, customers will be more inclined to adopt MASS and their adoption will heat the market for these solutions, increasing the competition and encouraging a network formation.

The network will ensure both areas of knowledge about the technology and the market will improve, which will improve the quality and performance of the technology, and once more fuelling adoption. Once the technology is used by more vessels, it will be easier to evaluate its impact on safety, fuel savings and CO_2 emissions and if the impact is positive, it will improve even more the cost-benefit, driving further adoption.

At the moment adoption becomes common in certain niches, it will become easier to prove the reality of MASS selling proposition, such as efficiency, fuel-saving and safety, demonstrating its quality. The complementary products and services will then influence MASS large-scale diffusion because insurance policies will have more interest in the technology. Still, if the existing technology network is available, complementary products will already be available, acting as will an encouraging factor to adoption.

Finally, some operational aspects might pose a barrier to the diffusion of unmanned vessels. However, given the increase in knowledge about the technology and its market application, combined with the expected propulsion changes mentioned in section 3.4.2 IMO Greenhouse Gas Strategy it is unlikely that operational aspects will be an issue. Even if the barrier still exists, it will mainly affect the adoption of unmanned vessels, not the adoption and diffusion of other degrees of control MASS.

As a result, given the chain of events likely to happen if international institutions regulate the use of MASS and grant permission for crew reduction, completing this building block will set all the other ones to move in the correct direction.

7.2.4 Commercial Pathway

Despite the efficient path that unfolds with the regulation of MASS and permission to reduce the crew, this scenario is rather unlikely. Without accidents or events to change the course of the regulatory bodies, the recognition of MASS and the authorization of reduced manning upon its use will take a long time if there is no pressure from companies offering MASS solutions, as well as companies willing to adopt MASS. This commercial pathway focus on what companies offering MASS solutions can do to drive MASS adoption without depending on the international regulatory bodies.

The pathway to diffusion uses the strategies proposed in Table 14- Strategies to Surmount MASS Barriers, considering Table 16- Influencing Factors Importance Rank as a guideline to which steps should be taken first in the route to MASS diffusion. The route must start with overcoming the cost-benefit barrier. Since demonstrating the cost-benefit without adoption requires the use of the technology, an alternative is to focus on the Top Niche strategy which, as mentioned in section 7.1.2 Cost-Benefit, focus on particular niches with different needs than the broad market.

7.2.4.1 Overcoming the cost-benefit barrier with niche applications

These niches would be survey vessels, military vessels, ferries and possibly leisure yachts. Survey vessels, as mentioned in section 4.4 Survey Vessels can be considerably reduced in size if they do not need to accommodate the crew, which allows a slimmer and cheaper design. In addition, the crew onboard survey vessels only steer the ship since the survey equipment is already automated. From the regulatory perspective, these vessels mostly operated in a controlled environment, reducing the impact of regulation. Therefore, for this niche, not only vessels can become unmanned, but its MASS design becomes cheaper, overcoming the cost-benefit barrier, encouraging adoption in this niche.

The other abovementioned niches, military, and ferries are operated by governmental institutions that have no focus on profitability. For these institutions, the capability of operating the vessel with a reduced crew, in the case of the military, and to offer public transport has higher priority, tipping the scale of the cost-benefit towards the adoption of MASS solutions. The focus on this niche could also be characterised as subsidised, given the public nature of the service offered by governmental institutions.

Finally, the customers buying leisure yachts have no focus on cost-benefit given the nature of the activity for which the vessels are used. This focus would deem the crew reduction unnecessary, opening an opportunity to become a niche for MASS adoption (Interviewee 14, 2021). The adoption of this niche, nonetheless, requires further research in terms of what factors affect the adoption of these vessels, as a non-commercially oriented niche within the maritime industry, other factors might surface, such as price.

7.2.4.2 Preparing maritime sector for MASS

Once MASS starts to be used in niche applications, more data will be collected by the AI algorithms, allowing the companies to prove MASS efficiency and safety, favouring the cost-benefit and the socio-cultural aspects of the TIS. To ensure the cost-benefit is also achieved to customers focused on financial return, companies offering MASS solutions can collaborate with insurance companies, to ensure special insurance policies to vessels adopting MASS. In addition, work together with local regulatory bodies to allow MSM reduction in national flags and territorial waters.

These steps, however, do not enhance the knowledge and awareness about the technology and market, which hampers the network formation and affects customers' will to adopt MASS. To overcome these barriers, a combination of Educate and Digital Demo Experiment & Develop strategies, mentioned in sections 7.1.1 Quality & Performance, 7.1.4 Customers and 7.1.6 Safety can be adopted.

To increase the knowledge and awareness about the technology and market, companies can capitalise on the double encouraging aspect of the Natural, human, and financial resources as explained in section 6.2.3 Natural, human, and financial resources. At the same the crew shortage promotes the adoption of MASS, the available funding from national and international MASS projects promotes the research on the field. Research can influence the knowledge and awareness of the technology, as well as the knowledge of its application.

To achieve this goal, MASS companies can pursue partnerships with research centres, universities and students willing to research different aspects of the technology. Since formal relationships with research institutes and universities may require more time, an easier path would be direct contact with students by offering thesis internships. Students, guided by their mentors, will research the topic, offering an overview of current literature and possibly a solution to a company-specific problem, or a new perspective in the MASS TIS, as this is constantly evolving. In the worst-case scenario, if the result of the students' research has no commercial application, his/her mentor became acquainted with MASS, increasing the knowledge and awareness about the technology.

The improvement in the MASS body of literature stimulates the formation of a technology network, that in turn will enhance the research about MASS, its characteristics, and applications. This network can be fostered even more with digital demonstrations about MASS capabilities. A virtual environment in which companies can showcase their MASS solutions to the public that otherwise would not understand how MASS affects vessels and their operations, as explained in section 7.1.1 Quality & Performance. The virtual technology demonstrations can also serve as a testbed to insurance companies since these will also need confirmation of accident reduction and other benefits before offering differentiated MASS insurance policies. From a complementary service perspective, this digital space can also be used to offer MASS courses specific to seafarers that will operate the equipment onboard.

This Pathway addresses the building blocks progressively, counting on their interconnectedness to remove or diminish the barriers in the current TIS. The use of the technology in a market niche with a different cost-benefit analysis than a simple ROI, combined with knowledge enhancing strategies set the TIS in motion towards the large-scale diffusion.

7.3 Pathways Overview

To answer research question 5, “What are the potential pathways to remove barriers and capitalize on encouraging factors to autonomous ships technology?” explained in sections 7.2.3 Institutional Pathway, and 7.2.4 Commercial Pathway, most of the previous chapters in this research have been used. Chapter 3. Autonomous Shipping Technology presented the MASS TIS overview and chapter 4. Current MASS Applications explained the current applications of MASS, both set the context to chapter 6. Factors Affecting MASS Diffusion

The pathways also build upon the strategies suggested in section 7.1 Overcoming Hampering factors to overcome MASS barriers and the relationships among the building blocks and influencing factors presented in section 7.2.1, ensuring a route that simultaneously tackles various barriers to MASS diffusion.

The result was 2 different pathways, an institutional one explained in section 7.2.3 Institutional Pathway and the commercial one detailed in section 7.2.4 Commercial Pathway. Whereas both aim to achieve MASS large-scale diffusion, the institutional fully depends on the maritime legislation of MASS and permission of crew reduction. The commercial pathway includes collaboration with the national regulatory bodies, as well as efforts to increase the knowledge and awareness of the technology and market applications. Both pathways, however, rely on the promise that all potential benefits of the technology will be proven real when AI has learned enough to achieve safety, efficiency and fuel reduction. If that is not the case, a completely different chain of effects will most likely unfold, affecting the TIS and the diffusion paths.

The answer to research question 6 “How can these pathways be used to facilitate autonomous ships technology diffusion in other application niches?” a similar path to the answer of research question 5 was taken, however with a focus on the identification of suitable niches, which are survey vessels, military, ferries and leisure yachts, explained in section 7.2.4.1 Overcoming the cost-benefit barrier with niche applications. As described in section 4.4 Survey Vessels, survey vessel applications already have a valid cost-benefit. The other niches have a different perspective on cost-benefit, as ROI is not the most important aspect of it. For military applications, MSM regulations are not a barrier and for ferries, this obstacle can be surmounted with local regulations implemented by the government making use of the ferries, since they mainly operate in territorial waters. Finally, the leisure yachts are vessels used for pleasure and not for commercial activities, having a different perspective on cost-benefit. For this last application, a better overview of the leisure yacht environment must be developed.

8. Conclusion & Discussion

"How can MASS reach diffusion within the maritime industry?"

1. *What are the characteristics of the current applications of autonomous ships?*
2. *In which pre-diffusion stage is the autonomous shipping technology?*
3. *What are the actors and factors affecting the adoption and consequent diffusion of MASS?*
4. *How could actors and factors hampering autonomous ships be surmounted?*
5. *What are the potential pathways to remove barriers and capitalize on encouraging factors to autonomous ships technology?*
6. *How can these pathways be used to facilitate autonomous ships technology diffusion in other application niches?*

8.1 Conclusion

MASS is still under development, a characteristic of technologies in the pre-diffusion phase and despite being regarded as an important solution for avoiding maritime accidents, this feature is not yet fully proven. From the perspective of the shipowners, its adoption is also not straightforward, since safety enhancement is not yet guaranteed, and its financial benefit is not easily calculated without reducing the number of crew members on board. This reduction needs to be, at least, approved by the national authorities to become interesting to the shipping companies. However, given the size of the IMO and the differences between the goals of its members, expectations that international regulations will be changed soon are very low.

Chapter 4. Current MASS Applications describes the current applications of MASS, which are mainly tests and prototypes. An exception of the application in the survey vessels, which is currently a commercial product offered by at least 3 companies: Kongsberg, Wärtsilä and Sea Machines. The products of the 2 first companies were described in chapter 4, while the other one was mentioned by the sales manager in one of the interviews and it is said to be fitted in existing vessels. Accounting tests and commercial products as current applications, all share the fact that they work in a controlled environment and all companies are in pursuit of some type of cost reduction.

On the one hand, the Maersk Vistula test tries to ensure a virtual line of sight, focusing on stacking more cargo onboard without touching the size of the crew. On the other hand, the Yara Birkeland, Svitzer Hermod and the Recotug Projects focus on unmanned operations with the support of SCCs.

The tests with the Factofour and IntelliTug are Somewhere in between, aiming at operational efficiency and consequent crew reduction, but no intentions to remove the crew from the vessels. It became clear that long-haul vessels are not yet interested in MASS, given the small contribution of the crew to its operating costs.

The survey vessels are available for sale in the market, fully unmanned they can be operated from SCC or a vessel nearby. Because they no longer need accommodation for the crew, survey vessels' design was streamlined to be more efficient, reducing costs in the operation. Therefore, the answer to research question 1: "What are the characteristics of the current applications of autonomous ships?" Is that MASS applications are currently performed in a controlled environment and with financial purposes, either to reduce costs or increase profit. The survey vessels currently achieve cost savings in their slimmer MASS design and the unmanned operation.

The current MASS applications are an important aspect to define where the technology stands regarding its diffusion. Chapter 5. MASS Pattern of Diffusion evaluates where MASS stands within the pre-diffusion model, once it neither suits the definition of technology in the large-scale diffusion phase suggested by Rogers (1985) nor Ortt (2010), both detailed in section 1.3 Literature Review. The chapter builds upon chapter 4. Current MASS Applications where MASS current applications are described, using this knowledge to determine the pre-diffusion phase of MASS.

The MASS concept dates from 1898, but only in 1980, the decision-making capacity was added to the initial concept of remotely controlled vessels by the use of AI, which as explained in section 3.2.1 Technological Principle, is the basis of MASS. Since the Yara Birkeland is a pilot project and it is not yet operating, MASS introduction to the market was considered to be 2019, when Kongsberg announced its product Sounder on its corporate website. There is no large-scale production of MASS yet, besides the survey vessels, the applications are mostly tests. Therefore, it is possible to conclude that MASS is currently in the pre-diffusion adaptation phase, answering research question 2.

Section 1.4.4 Building Blocks Framework[2] is based on the BBF developed by Ortt & Kamp (2021) and shows that a breakthrough technology must overcome barriers to its adoption to achieve diffusion. Chapter 6. Factors Affecting MASS Diffusion presents the barriers to MASS diffusion under the BBF perspective based on the data collected in the interviews and the literature presented in section 1.5 MASS Literature Review. The conclusion shows that nearly all building blocks suggested by the BFF are suitable to evaluate MASS TIS. Small adaptations were made in the BBF to ensure complete appropriateness to MASS, which can be seen in Table 18 - BBF X MASS actors & factors. These adaptations were the addition of Safety as a building block, the removal of complementary products and services as factors directly affecting MASS diffusion and the adaptation of the term Price building block to Cost-benefit, as price does not affect the adoption of MASS.

BBF Building Blocks	MASS Building Blocks
Quality & Performance	Quality & Performance
Price	Cost-Benefit
Production System	Production System
Complementary Products & Services	
Network formation & Coordination	Network formation & Coordination
Customers	Customers
Innovation Specific Institutions	Innovation Specific Institutions
	Safety
BBF Influencing Factors	**MASS Influencing Factors**
Knowledge and awareness of technology	Knowledge and awareness of technology
Knowledge and awareness of application and market	Knowledge and awareness of application and market
Natural, human, and financial resources	Natural, human, and financial resources
Competition	Competition
Macroeconomic and strategic aspects	Macroeconomic and strategic aspects
Socio-cultural aspects	Socio-cultural aspects
Accidents and Events	Accidents and Events
	Complementary Products & Services
	Operational Aspects

Table 18 - BBF X MASS actors & factors

Small changes were also applied in the influencing factors list proposed by Ortt & Kamp (2021). Besides the addition of the complementary product and services as influencing factors, a factor named operational aspect was added to the list to represent issues arising from the unmanned operations.

Despite not being important in the initial stages of MASS adoption, this factor influences the operations of unmanned MASS large-scale diffusion. The answer to research question 3: “What are the actors and factors affecting the adoption and consequent diffusion of MASS?” is the modified list of actors presented in Table 18 - BBF X MASS actors & factors.

Knowing the factors affecting MASS adoption is important to overcome them and achieve diffusion. Therefore, in chapter 7. The way to Autonomy, the list presented in section 6.3 Factors Affecting the MASS adoption was used to define market introduction strategies focusing on overcoming the barriers presented by the absence or incompleteness of the building blocks. The strategies used were explained in section 1.4.5 Technology Introduction Strategies. Where necessary, these strategies were adapted to the MASS TIS.

Demo experiment and Develop Niche Strategy, used to enhance awareness of the customers and increase knowledge about MASS, was adapted into a digital version, given the impossibility of demonstrating MASS easily to the public. Since none of the 10 niche strategies proposed by Ortt, Langley, & Pals (2013) aimed at Network formation and coordination as a barrier to diffusion, a strategy was created to overcome this MASS barrier based on Dasaratha (2019) study about network formation and coordination. The list of strategies to overcome each of the barriers to MASS adoption and consequent diffusion answers research question 4 “How could actors and factors hampering autonomous ships be surmounted?” is presented in Table 14- Strategies to Surmount MASS Barriers.

To ensure a pathway to diffusion comprises all building blocks and influencing factors of the TIS, and is aligned with Bergek et al studies about TIS explained in section 1.4.3 Technological Innovation System (TIS), the relationships among the building blocks and the influencing factors were explained in section 7.2.1, depicted in Table 15 - Relationships between Building Blocks & Influencing Factors and Figure 27- Relationships between building blocks & Influencing Factors. The importance of the influencing factors was also highlighted in Table 16- Influencing Factors Importance Rank, leading to the validation of the BFF to MASS as a breakthrough technology and the confirmation that MASS is in the adaptation phase. Both conclusions come from the order of importance of the influencing factors, denoted by the higher importance of the BFF influencing factors and the non-influence of a MASS factor (Operational Aspects), that will only affect the large-scale diffusion and not the adoption of the technology.

Chapter 7 answers the research question 5 “What are the potential pathways to remove barriers and capitalize on encouraging factors to autonomous ships technology?” with 2 possible pathways to the diffusion of MASS, the institutional and the commercial pathways. Whereas the institutional pathway depends only on the regulatory bodies allowing crew reduction for vessels enhanced with autonomy, the commercial focuses on many other aspects of the TIS. It is valid to mention that both pathways rely on MASS delivering the potential enhancements in safety and efficiency, otherwise the differences in the TIS will be as such that the proposed pathways will no longer be valid.

The commercial pathway combines the strategies proposed in section 7.1.7 Strategies to Surmount MASS Barriers into one pathway, suggesting the adoption of Top niche strategy for niches with different perspectives on cost-benefit, as followed by a Digital Demo experiment and an Educate strategy focusing on contact with students and researchers to increase the MASS body of literature. These actions should be taken simultaneously to the adoption of a geographic strategy to ensure crew reduction in territorial waters and national flagged vessels and the collaboration with insurance companies to ensure MASS cost-benefit to the local maritime industry.

Chapter 7 closes with the answer to research question 6 “How can these pathways be used to facilitate autonomous ships technology diffusion in other application niches?”, which is to focus on the survey, military, ferries and leisure yachts as niches to start the application of MASS because these niches have a different perspective on cost-benefit than the cargo vessels, or in the specific case of survey vessels, can already capitalise on the cost-benefit currently offered by MASS.

Finally, the combination of all research questions answers the main research question: “How can MASS reach diffusion within the maritime industry?”. MASS can reach diffusion in the maritime industry by following the commercial pathway established to take advantage of the current encouraging factors and overcoming the barriers to its adoption. If the IMO change the regulations and permit manning reduction for autonomous vessels, MASS adoption will be achieved with little effort from the companies offering MASS solutions. This possibility, however, is not realistic, leaving the laborious commercial pathway as a guideline for the companies interested in MASS reaching diffusion.

8.2 Discussion & Future Research

8.2.1 MASS Social and Economic Impact

While the focus of this research is solely finding a pathway to MASS diffusion, the impact of this diffusion cannot be taken for granted. Since the basis of the cost-benefit analysis is crew reduction, an obvious point to consider is the economic impact of this reduction for the so-called sailing nations, from which many seafarers come from. The idea that seafarers work will transform into an SCC operator disregards some important aspects of maritime life and the global economic impact of the maritime industry.

The first one is the employability of those seafarers who hold lower levels of education, whose tasks include ensure the vessel is rust-free and painted, for example. It is very unlikely these seamen will turn into SCC operators since the navigational and engineering knowledge will be necessary for the job. Another implication is the international nature of the maritime industry, the majority of a crew member on Dutch-flagged vessel does not need to hold Dutch nationality, neither a visa to work in what international law considers Dutch territory.

This is not a characteristic of the Dutch flag, but of the entire industry, vessels are often manned with many different nationalities. Most likely, the SCCs will employ operators who live near the control centre, making the function unachievable for many nationalities. Adding the fact that most countries heading the MASS research are already economically developed countries, MASS might contribute to increase the global economic differences.

Finally, maritime education needs to be adapted to ensure the adoption of MASS. The knowledge and awareness of the technology were highlighted in the suggested pathway, but seafarers' education is paramount for the acceptance of the technology in the industry. Therefore, the inclusion of MASS understanding and operation in maritime academies will ensure a better acceptance of the technology not only by the next generation of sailors but also by the current generation of maritime unions.

All these aspects shed a different light on the reasons why IMO has not yet regulated the use of the technology and allowed crew reduction, despite the factors mentioned in the research, such as proven safety enhancement. Understanding this more social perspective of MASS is attractive to further research studying the IMO policy change aspect necessary for MASS adoption. Such research could also validate the institutional pathway proposed in this report.

8.2.2 MASS & other technologies

From a less social and more technological point of view, it is interesting to discuss the future of the maritime industry itself. With the development of technologies as 3D printing, long-haul sea transport might experience a size reduction, despite the positive view of the current ordering cycle. This reduction would, remarkably, encourage the adoption of MASS in territorial waters, as these will tend to increase if products are built locally, instead of the current overseas trend of manufacturing. The relationship between these 2 breakthrough technologies and their combined impact in both TIS can also be an interesting aspect for further research.

The initial focus on survey vessels as niche also requires attention, since these vessels operate in a more predictable environment than the regular cargo vessels and became much smaller. This difference might impact AI learning of the vessels' response and encounter less "misbehaving" human-controlled vessels than the reality would show. Both effects can impact would result in a slower learning curve for the algorithms, which would diminish the speed at which MASS can prove its potential.

8.2.3 Managerial & Academic Contribution

This study contributed to the managers and entrepreneurs in the maritime industry. Not only for those that can make use of the pathway developed to MASS diffusion but also to enhance the knowledge and awareness about MASS and its market applications. Shipowners, seafarers, and entrepreneurs can use this research as a guide to better understand the industry in summer 2021. Another important contribution, which is valid for both academic and managerial perspectives is the inclusion of the seafarers' perspective in the research, adding the operational point of view and contributing to close the gap of knowledge in the triad academic, operational, and managerial.

Academically, this research adds value to the literature by validating the use of the BBF and the PDM for a technology that was not yet evaluated with this framework and model. It also adds the perspective of a business-to-business industry, in which the technology buyer is not the final user, and the final user has little to no influence on the technology he/she will work with. As a business-to-business sector focused on operational excellence, the maritime industry has a strong focus on Cost-benefit and safety, which also guides its technology adoption.

Regarding the BFF modifications, the change of complementary products and services factor from building block to influencing factor might contribute to the definition of an influencing factor in future research. The perspective of direct influence in the adoption and further diffusion of the technology was used to change the category of this factor. Since complementary products have no direct effect on the intention of MASS adoption, they could not at as a building block, since their absence do not hamper diffusion on its own. Considering building blocks directly affect diffusion, this factor could not be a building block to MASS TIS. However, complementary products and services do impact another building block, namely cost-benefit. A characteristic of the influencing factors is exactly their ability to impact the presence of a building block, leading to the conclusion that, for MASS TIS, complementary products and services act as an influencing factor rather than a building block.

This research has also added the perspective of importance to the BFF building blocks in MASS TIS, a perception that can be added to the framework and used in the analysis of any other breakthrough technology. The goal of this addition was to ensure the pathway developed to MASS diffusion would address the most important building blocks first. This extra information added to the BFF helped the overview of the relationships among MASS TIS actors and factors, showing that not every building block has the same effect on the MASS diffusion. A suggestion would be to use the important factors in other technologies, despite the industry, to ensure its collective validity.

The development of a strategy to overcome the network formation and coordination building block can also be considered an academic contribution of this study. The initial aim of this research was to use strategies suggested by the article Ten Niche Strategies To Commercialize New High-Tech Products (Ortt, Langley, & Pals, 2013). However, none of the strategies proposed by this study proposes how to overcome the lack of network formation and coordination. There might be some reasons for this, the first one is that the article only considers a network of suppliers. While the definition of the BBF is also mainly focused on suppliers, it involved other actors as well, broadening the meaning of network.

For the interviewees, however, the concept of a network was even broader, considering the interaction between the companies and knowledge institutions within the MASS TIS. Within the MASS network, as well as in the supplier network proposed by Ortt, Langley, & Pals, knowledge is paramount for network formation. The difference is the will to share knowledge, which is reduced when companies have an incentive to keep their developments secretive. This different perspective required a new strategy because of the incentive to secrecy stopping the formation of the network. This strategy was then based on a study about fostering network formation and overcoming the secrecy barrier stopping companies from collaborating. This new definition of a network and new strategy should be further researched to evaluate its validity within other TIS contexts where collaboration between companies is also part of the network meaning.

Finally, the last academic contribution was the implementation of a pathway to combine the introduction of niche strategies into one route that suits the development of breakthrough technology. This pathway capitalizes on encouraging factors to overcome TIS barriers systematically. It is a logical option because it not only recognises but employs the interconnected nature of the actors and factors in the TIS of breakthrough technology, which changes if the TIS changes. A pathway capitalizes on the actors and factors relationships, increasing the chance that the combined strategies will achieve the final goal of large-scale diffusion. The adoption of this new last step in the evaluation of a technology TIS also serves as a topic for further research, once it can become a framework for pathways to large-scale diffusion if its approach is validated to other industries and technologies.

8.2.4 Internal, External Validity and Academic Rigour

Given the clear relationship of the MASS TIS with the models used, namely the PDM, the BFF and the Bergek et al concept of TIS, this study can be categorised as internally valid. The external validity, however, still needs to be proven, since the number of interviewees was very small compared to the vast industry and the majority of them were part of the Dutch maritime industry. Similar research in another country, and/ or with a bigger number of interviewees is suggested to validate the findings of this research.

Another future research suggestion to increase the external validity of this study and the BBF would be to apply the suggested BBF adaptations into other business-to-business industries. That would have a twofold contribution: Validate if other business-to-business industries have the same operational focus on safety and cost-benefit. And strengthen the external validity of the BBF, proving its suitability to consumer breakthrough technologies as well as industrial technologies.

Academic rigour could have been more strict in this research and, as a result, its repeatability was affected. More attention was given to the data collection than to the recording of how the data was collected, especially in the data collection about the current MASS applications. As a breakthrough technology, there are no academic cases to study from, making the open world wide web the only source available, as many companies did not respond to the contact to participate in this research. Despite collecting important data, the focus on rigour was reduced during the web searches, which jeopardizes the repeatability. Finally, the academic rigour was also lacking in the analysis of the interviews. The selection of interviewees and the data collection were performed methodically. However, the analysis of the interviews focused more on content than on repeatability, not detailing each step followed during the analysis process.

Both episodes of lack of rigour reduce the external validity of this research, urging for another study of similar nature with more academic rigour to ensure the repeatability and evaluate better the external validity of this research. On the other hand, given the speed at which MASS TIS is changing, any research repeated in the future about this technology would present different results, therefore reducing the impact of lack of recording in the data collection process.

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10. Appendix

10.1 Semi-structured interview questions

1. Could you briefly introduce yourself and explain a little about your current work and experience?

2. How do you assess your current work is related to or affected by AS technology?

3. Could you present your point of view about autonomous ship's technology?

4. On a scale from “much less” to “much more” how would you compare your knowledge about AS technology?

   - How much do you know about AS in comparison with your friends?

Much less	Less	Similar knowledge	More	Much more

   - How much do you know about AS in comparison with your colleagues?

Much less	Less	Similar knowledge	More	Much more

   - How much do you know about xxx in comparison with experts?

Much less	Less	Similar knowledge	More	Much more

5. What are the current commercial applications of autonomous shipping in your line of work? Based on your understanding, why these are the current applications?

6. Would AS technology apply to other maritime sector operations other than the current applications? If yes, which ones?

Possible options (if none comes up)

Explain what are actors and factors, and large-scale adoption (diffusion).

7. In your point of view, what are currently the main drivers and barriers to the use of AS technology?
8. What are the main actors and factors currently present or partially present that hamper the large-scale adoption (diffusion) of the technology in your organization and sector?
9. What are the main actors and factors currently present or partially present that encourage the large-scale adoption (diffusion) of the technology?
10. Among the mentioned factors (repeat the factors), how would you rate their importance level?

Not at all important	Slightly Important	Moderately Important	Very Important	Extremely important

11. Which factor(s) would you start tackling first? Why?
12. Are there possible solutions for the hampering factors you mentioned? If yes, could you elaborate on these solutions and their impact?
13. Are there possible ways of benefiting from the drivers you mentioned?

Explain the building blocks model and the 7 building blocks:

- Quality/ performance
- Price
- Production System
- Complementary products or services
- Network formation and coordination
- Customers
- Institutions

14. Considering the maritime industry, specifically AS technology. Are all the mentioned building blocks applicable? If no, which ones are NOT applicable?
15. Are there important building blocks that were not mentioned? If yes, which ones?
16. For AS technology, could you categorise the building blocks in present, partially present and absent?

Present	Partially Present	Absent

17. For the factors you mentioned that are partially present, or fully absent, could you identify a root cause for their absence or inexistence?

18. You have identified ___________ as barriers and _________ as drivers for the AS technology. Is it possible to categorise these factors within the 7 mentioned building blocks? If so, in which categories would you place them?

Briefly explain the influencing factors within the building blocks model.

- Knowledge and awareness of the technology
- Knowledge and awareness of the application in the market
- Natural, human and financial resources
- Competition
- Micro-economic and strategic aspects
- Socio-cultural aspects
- Accidents and events

19. You have mentioned barriers and drivers for AS technology (repeat what was mentioned). Could you identify the underlying causes for these barriers?
20. Are these influencing factors (Show influencing factors list) important to the AS technology? Why?
21. Do you foresee AS as the “normal” for the maritime industry in the future?
22. If yes, when?
23. Now you have seen many barriers and influencing factors, do you see additional solutions to deal with hampering factors or to benefit from drivers?
24. Do you have any extra remarks about the diffusion of AS technology that was not asked, or not mentioned in this interview before?

10.2 List of Interviewees

Interviewee 1 – Kongsberg Business Analyst

Interviewee 2 – Captain AI Senior Manager

Interviewee 3 – Damen Programme Manager

Interviewee 4 – Harbour Infrastructure Specialist

Interviewee 5 – Shipping Technology Technical Senior Manager

Interviewee 6 – Oil & Gas Offshore Supply Captain

Interviewee 7 – Shipping Technology Senior Manager

Interviewee 8 – PhD Candidate Autonomous Vessels

Interviewee 9 – TU Delft Professor & MASS Researcher

Interviewee 10 – Captain long-haul container ship

Interviewee 11 – Boomsma Shipping Senior Manager

Interviewee 12 – Sea Machines Business Development Manager

Interviewee 13 – Chief Engineer offshore wind energy

Interviewee 14 – Naval System Integrator

10.3 Example of Interview Summary

All Interviewee summaries are available for further evaluation upon request. Email Mariah CL Kurtinaitis Joukes to request at: mariahkurtinaitis@gmail.com

Summary of Interview – Damen Programme Manager

Two interviews were held with this interviewee on the dates 04-05-2021 and 11-06-2021

First Interview 04-05-2021

Experience of the interviewee

I am a programme manager for automation and smart shipping, which is part of the programme of smart for smart ships, which is part of our research and development department. We are a small team of programme managers, which are running the three main programmes connected ship, simulated ship and automated ship. My team has multiple smaller projects focused on new technologies, namely adapting new technologies to the ship types, as well as on the selection process on what is interesting and useful for our customers. A big part of our daily work is to have discussions on business cases, whether it makes sense or not to focus on a specific technology. In general, I am more focused on the technology which is available in the market for autonomy, even more in which markets it's interesting to implement certain technologies or at least autonomy to a certain level.

Company Focus

We are working as a centralised unit for the complete company to support all shipbuilding entities within the Damen group by making the ships smarter. As a company, we are also moving a little bit from the more traditional transaction-based business model. We are moving to a more service-based model where we want to support ship to the total lifetime, also the technology, like connectivity and database solutions support. That allows us to support customers with our knowledge during the ship's operational lifetime.

Reason for application

It depends on the ship type and what the ship is supposed to do. We are talking with ferry operators and in the ferry market, we see that the market readiness level is quite high that the market is ready to adopt autonomous solutions, especially in Scandinavia. They are ahead, but they are looking for autonomous ships solutions. Tug boats are looking more as support for support systems remotely in part of the mission, for some parts they might be ready, but the towing operation itself, they are not ready to do that autonomously. The real driver for adoption depends on the ship operation.

Drivers for MASS adoption

Safety is not a driver, it is a preconditional item, you must only increase safety, for everything you do, you must increase safety. Otherwise, it is not acceptable. The main drivers are efficiency, effectiveness, in terms of doing more jobs within the same time, and the utilisation of the fleet. For example, a tugboat is active for about 5 or 5 hours a day, if you can optimise that, you can do more jobs. It is a driver I see everywhere.

There are also other reasons, as CO2 reduction, replacing trucks from the roads. If the technology can reduce people onboard, it becomes interesting for smaller crossings. On the ferries, they could start the ferry again if the ferries were autonomous, but it is not a valid business case today. It all comes down to lowering costs and increasing gains. Always.

Propulsion

The hard part for shipowners today is what kind of propulsion to choose. Because the standard today maybe tomorrow outdated, the day after tomorrow, there's new technology coming in. The shipowners building a ship today know that 5 or 10 years from now the ship is not compatible anymore with the market standards. That is a problem for the shipowner, for the financial companies, and the insurance companies and the clients. It is a problem for the total ecosystem.

From that perspective comes the need that the ship must be upgradable or updatable during her lifetime. But then there is the question of when is the right moment to do it? And then the smart solutions come in because then measuring the complete ship will help you analyse it and predict what, a certain change will bring. How you use your ship is also part of that, how to fill your ship optimally, for example, autonomous systems can help there. The systems are now focused on preventing collisions, but in the future, they could be capable of loading in an optimal way to reduce footprint. The complete loop of automation is always receiving the data first, analysing the data, making predictions on the decision, decision selection, and then executing it. And that can help in lowering the footprints or making decisions on what to do with your ship in terms of change of propulsion.

Autonomy and ship's propulsion grow separately because propulsion is modular. The biggest influencer on propulsion is the ship's mission. For short sea, electricals are a good option. But for longer trips, it is no longer possible. Not with the current batteries.

MASS investment

To make a ship smart, fitted with a connectivity platform linked to the cloud and sending that to shore is not expensive. It depends on the ship size and how many data points, but the costs would be between 10 to 100 thousand euros in a vessel that costs 12 or 15 million. Autonomy functionality is more complex, these ships are not there yet, they are only projects, but nobody has the full scope of autonomy. But in this case, it would cost more because the shore infrastructure would have to be adapted as well, then it would turn into millions of euros of investments.

Current use of MASS

It is an interesting and complex project, but it did not succeed in being fully autonomous. In the end, they put a small wheelhouse to be able to moor manually. The only vessels sailing autonomously are survey vessels up to a 10-metre maximum. Ferries and cargo vessels that are only sailing from A to B are only in project phases.

Autonomy

The most difficult part is the mission of the ship. Automate the navigation from A to B is not that difficult, but the other tasks of the crew are more complex. The reports, the engine, the operational side… everything needs to be automated. Everything needs to be made stable and safe, that is complex.

For enhanced situational awareness the autonomous system can be very useful. For example, the crew transfers to offshore windmills, ships often need to sail for 6 or 7 hours with passengers to reach the destination and drop them off. The drop-off is the difficult part, the navigation could be autonomous. One could argue that by relaxing during transit, the crew can rest and have a safer mission when it arrives on location. The same works for container vessels, everybody agrees that if the crew is fully awake, they can make better decisions than any system, but not everybody can focus for 10 hours. Especially when the work becomes dull, then it is easy to make mistakes. In these cases, an autonomous system will give support, controlling not only the steering but the propulsion also. That would not be a fully autonomous system, it is more a smart autopilot. If that is affordable, it would be interesting for shipowners to increase safety and possibly reduce crew.

Autonomous Cars x Vessels

The difference with the cars is because the only goal of the car is going from A to B, right, like a ferry or a container vessel. But that's all the car has to do. What you see in shipping is that those ships, which only do the A to B part like a ferry, are focusing on autonomy and making the crew supervisors instead of operators. But all the other ship types, ships that have a complex mission to perform ere not looking for autonomy, maybe crew reduction, or maybe even not.

Crew Cost & Regulations

Not every crew is as expensive as in Western Europe. In some countries, the crew is not expensive at all. For some countries, their crew must be onboard. There are regulations to create and keep these jobs onboard. Companies have different drivers, some companies use the fact that they bring jobs to the country as a selling point for their service. They have no interest in autonomy. That makes the maritime markets so diverse, almost every company has its own drivers.

Second Interview 11-06-2021

Interviewee relationship to MASS

We are working on the digitalization of the ships in 3 main pillars, which are: connected ship for data coming from the ship to shore and analysing that data. The second pillar is the simulation of the data looking to the future. And the third step is automation. With the automation, we bring back all the monetary gains from the previous and historic data, we can bring it back to the ship, advice the ship, and as the final step, execute the advice and close the loop of automation. I short, working towards the autonomous ship, that is possibly the final result of what we are doing.

The autonomous ship is not the goal for us, our work is focused on all the individual modules which help the individual bridge, helps to make the autonomous ship in the end. But every module we develop or co-develop with the markets is contributing to the next step towards autonomy. Our goal is to support the client to improve the quality, utilisation, efficiency and effectiveness of the ship. We do that by building a ship that is ready for the future which is upgradeable and updatable over time.

MASS point of View

On the technology level, there are several solutions on the market, which have high TRL (Technology Readiness Level) which makes a big part of autonomous sailing possible. Not the full scale yet, from the various autonomy levels, which the regulating bodies are using, I don't think there's a solution with which is capable of doing everything, which is level five for IMO, for example. That's not yet three. But the prototypes are close to that. All the single blocks are available in the market but have not yet a total solution built and tested.

Knowledge about the technology

- How much do you know about AS in comparison with your friends?

Much less	Less	Similar knowledge	More	Much more
				x

- How much do you know about AS in comparison with your colleagues?

Much less	Less	Similar knowledge	More	Much more
			x	

- How much do you know about AS in comparison with experts?

Much less	Less	Similar knowledge	More	Much more
		x		

Current Applications

All the projects that are running in the world for that are maybe at 90% level, at least for a full-scale cargo vessel or workboats doing their missions and sailing autonomously. Smaller ships, like the small hydrographic ships, are further but it's also a different market. On the technology level, the market is quite far, the difficult most difficult part is the rules regulation side, and the insurance side. Maybe also the financial.

There are some projects for full autonomy mainly in Scandinavia, as the Yara Birkeland. Kongsberg has 1 or 2 other vessels that they are building and executing. There is this vessel sailing autonomously from the UK to the USA, there are some tests in Singapore for remotely and autonomous vessels. There are also other smaller boats focusing on autonomous sailing, such as in the canals of Amsterdam.

Possible MASS Applications

It's all about why ships have their main focus, if the main goal of the ship is navigating, that's the easiest. So, a ferry is then high on the list because its mission is sailing from A to B. They also have fixed routes and fixed locations where to moor, so that's easier to adjust and to adopt. The complexity of the ship's mission counts, the more complicated, the higher the difficulty to become autonomous, sometimes maybe even impossible.

For lower levels of autonomy, the smaller boats are an ideal market because they are often sailing near the coastal area and inland waters, or short-sea. Their journey from A to B could benefit from partial autonomy. Tug boats can be done partially remotely. For the dull, boring, or not interesting for the human being, the autonomous systems can support the crew.

Encouraging factors

Safety – The system makes sure there is no collision anymore, it makes sure that the ship stops or steer a different way to prevent collisions. That's increasing safety directly.

Business Drivers – The only question with efficiency and efficacy is that it is difficult to prove the real result, to make a real business case from it. That is why the market is sometimes a little bit reluctant to adopt the solution.

Trust in the Systems – Shipping is quite a conventional business. So everybody is waiting to see how good the system really is. It's a driver, but it's not fully out there yet.

Insurance Companies can be a barrier and a driver. It can be a driver depending on how far the technology is. If the technology makes it safer and results in fewer accidents, is something insurance companies will be happy with.

Barriers

Legislation (SOLAS, STCW, Class Certification, Flag States) can be a barrier and a driver. They are currently a barrier because they are made for manned vessels without the current technology.

Cost of integrating a new system into an old system – the most difficult part is the integration of new systems into existing systems. So the cost of integration is high, and it's complex to calculate, it's also difficult to predict what the other systems will do. What we can do that with our simulation programme, for example. But that's also costly.

Cost-Benefit – if there is a good solution that is expensive but gives a good return on investment, there is no problem.

Availability of the technology (Proven Performance) – The technology is not yet proven, looking at TRL (Technology Readiness Level), it is not yet on level 9 when you look at full autonomy. It is not there yet, it is not a decision when you ager going to buy a ship, not a checkbox that says “autonomous ship” for 5 million euros. There is a tender running for an autonomous ferry in Sweden, with IMO autonomy level 3 and nobody has offered so far, because technically it is not feasible yet. The market wants to have it, but there is a gap between what the shipowners want and what the maritime market can offer. It is more complex than just the price and the technology, there are risks and expectations about the technology at the same time.

Hampering & Encouraging Factors Presence

Hampering	**Present**	**Partially Present**	**Absent**
Legislation	x		
Availability of the technology – Proven Performance			x

Cost of integrating a new system into an old system		x	
Cost-Benefit Balance		x	

Encouraging	Present	Partially Present	Absent
Safety	X		
Business Drivers: effectiveness & efficiency		x	
Trust in the Systems			x
Government Fundings	x		
Insurance Companies			x

Importance of the hampering and encouraging factors

Factors	Not at all important	Slightly Important	Moderately Important	Very Important	Extremely important
Legislation				X	
Availability of the technology – Proven Performance					x
Cost of integrating a new system into an old system		x			
Cost-Benefit Balance					X
Safety					x
Business Drivers					X
Trust in the Systems			x		
Government Fundings		x			
Insurance Companies		X			

The one that needs to be solved first is the commercial driver dor the shipowner,

Possible Solutions for Barriers

There is no single solution for all of them, it would be nice if we had. The most difficult one to solve is legislation, especially when you look at international legislation. If it is a local governmental issue, where the ship remains within the country is not significant, because the governments are willing to give exemptions. But internationally, it's quite difficult. If you look at job loss, and IMO discussions it is more complex.

Building Blocks

All building blocks of the model are important for the maritime industry

Building Blocks	Present	Partially Present	Absent
Quality/ Performance		x	

Price		x	
Production System		x	
Complementary products or services		x	
Network formation and coordination		x	
Customers		x	
Institutions		x	

Categories	**Actors & factors**
Institutions	Legislation
Network formation and coordination Production System	Availability of the technology – Proven Performance
Price Production System	Cost of integrating a new system into an old system
Price Customers	Cost-Benefit Balance
Quality/ Performance	Safety
Price Customers	Business Drivers
Quality/ Performance Customers	Trust in the Systems
Institutions Network formation and coordination	Government Fundings
Complementary products or services	Insurance Companies

Influencing factors

Influencing Factors	Actors & factors
Knowledge and awareness of the technology	Availability of the technology Trust in the Systems
Knowledge and awareness of the application in the market	Legislation Insurance Companies Trust in the Systems
Natural, human and financial resources	Business drivers Costs/Benefit balance Availability of the technology
Competition	Business drivers Costs/Benefit balance

	Availability of the technology
Micro-economic and strategic aspects	Business drivers Costs/Benefit balance
Socio-cultural aspects	It is a major aspect
Accidents & Events	Costs/Benefit balance Legislation

Social-cultural aspects are major influencing factors because it depends on location in the world if people

The competition will influence many aspects, its increase will increase quality and decrease prices.

Future of MASS

Mass will definitely take the position in the maritime industry. In 5 years there will be a few ships sailing autonomously in a commercial way. The bigger scale will not be full-autonomous, but partially autonomous. The interest from our customers today is already much higher than 1 year ago. People see examples and tests, so they are confronted and informed about the technology, they start to calculate what it means for their companies and the interest start to increase.

Cost of MASS

The cost to add some level of autonomy in a 25 metres boat is not an extreme investment, to make it fully autonomous and even unmanned will be very expensive. In the long term, it will be less expensive because we will be able to adjust the vessel design if it is unmanned. Then you don't need a bridge. But that is much further away. 25 or maybe 20 years from now. Tugboats and smaller vessels are easier, but large container vessels are further away.

The Crew

The crew will have a big influence. To ensure the systems work, if they deliver what they were designed for will depend on the crew's adoption. The adoption by the crew is not to be underestimated. If the crew does not agree or doesn't know how to use it, the system will not work optimally. It is something to look for, if a system comes to take over someone's job, it is natural to want to prove that they are better than the system.