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How to analyze the introduction strategies for radically new technological innovations? The case of Autonomous Shipping

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ABSTRACT: This article explores Maritime Autonomous Surface Ships (MASS) through the Technological Innovation Systems (TIS) framework to identify strategies for creating a market for this emerging technology. It examines the current state of TIS components for MASS and the factors shaping their development. Through a literature review and expert interviews, the article highlights key barriers, particularly the cost-benefit ratio, and suggests niche strategies to address barriers. Proposed strategies include the top niche strategy, lead user strategy, and hybridization niche strategy, aimed at overcoming challenges and facilitating broader market adoption of MASS in the future.

KEYWORDS: Autonomous ships, MASS, Technological Innovation System, niche strategy

1. Introduction

Radically new technological innovations represent an advance in technology that is so significant that either price/performance ratios are altered dramatically, or entirely new kinds of applications are made possible [1] [2]. Historical examples of such innovations in the automotive industry are hydrogen cars compared to cars with internal combustion engines. The diffusion of radical technological innovations differs from incremental innovations [3]. Radical innovations seldom start diffusing smoothly in an existing market. After the first introduction, an erratic process of introducing and withdrawing specific versions of the innovation in niche markets can be witnessed. It is remarkable how long it takes before radically new technological innovations start diffusing on a large scale [4-6]. This erratic process is often caused by a market that is full of barriers to large-scale diffusion. Another difference between radical and incremental innovations is the change in the socio-technical system required for large-scale diffusion. Radically new technological innovations often entail new complementary products and services, new customer groups and adapted institutional arrangements, for example. This means that a new market arrangement must emerge before large-scale diffusion of that radically new technological innovation is possible. The ultimate market arrangement is often unknown early on, because of uncertain progress in the development of technologies, complex and unpredictable patterns of competition between old and other new technologies. The socio-technical system changes around a radically new technological innovation can be explored using a Technological Innovation System framework [7,8].

This article focuses on Maritime Autonomous Surface Ships (MASS) in order to illustrate how to analyze the wider system around an upcoming market and derive introduction strategies into that market. It takes the work of two previous articles as a starting point. In [9], we concluded that the diffusion of MASS is hampered by several barriers and MASS is thus applied in small scale niche applications only, such as survey and ferry transport. So, MASS has not yet started to diffuse on a large scale [9]. In [10], we analyzed the wider sociotechnical system around the upcoming market for MASS. We used the Technological Innovation System (TIS) framework that can be used by maritime managers and researchers. This framework combines technological, economic, institutional and social aspects that are important for large-scale diffusion and relevant for strategy formulation. It contains seven so-called TIS building blocks of the socio-technical system from which new markets emerge [11]. We concluded that some important building blocks are still fully or partially absent that are required for large-scale diffusion of MASS [10].

However, a knowledge gap remains: to date, the literature has not explored the strategies that can be employed to spur the diffusion of MASS. The current article will investigate that. It extends the previous work by showing how several underlying conditions called influencing factors influence the status of the TIS building blocks for MASS. Based on the insight into the status of the TIS building blocks and the influencing factors we derive strategies to spur the diffusion of MASS. We focus on the application of MASS in commercial shipping rather than pleasure craft and on the societal and technological aspects that enable MASS as a whole, without detailing the enabling technologies that compose the various types of autonomous vessels. This leads to two research questions:

RQ1: What is the status of the building blocks that together form a Technological Innovation System (TIS) around MASS and how is that status influenced by influencing factors?

RQ2: How can potential (niche introduction) strategies be derived from the analysis of the TIS around MASS?

The research questions are scientifically relevant because the TIS framework provides a framework that can be used to analyze the context at the time a new market is emerging or does not even exist yet. That means the framework is an addition to the extant market research literature. The framework represents a (socio-technical) system perspective, but instead of most of the innovation system literature, it is not used to formulate policies for governments but to formulate strategies for companies [11]. The research questions are managerially relevant because the TIS framework and the strategies derived thereof provide an analytical tool for a situation in which standard market analysis instruments fail, and standard strategies are not applicable. As a result, many companies are found to fail in the situation of new and emerging markets for radically new technological innovations.

To answer these questions, we used a combination of literature research and two rounds of interviews with MASS researchers and practitioners. The unstructured and semi-structured interviews gave a broad perspective of the barriers and a detailed view of the barriers and their underlying influencing factors. To answer research question 2, we used the approach outlined in the work of Ortt & Kamp [11].

Our article is organized as follows: the theoretical notions are described in section 2, the method in section 3 after which results are presented in section 4. Conclusions, discussion and future research avenues are in section 5.

2. Theoretical background

In this section, we present a general TIS framework following the work of Ortt & Kamp [11]. The framework is used to assess potential barriers and their influencing factors during the process of development and diffusion of radically new technological innovations, such as MASS. In practice, barriers to large-scale diffusion lead to a pattern of development and diffusion that differs from the well-known diffusion pattern introduced by Rogers [12]. Instead of a smooth S-shaped diffusion curve, a more erratic pattern can be witnessed for diffusion processes of radically new technologies [13]. After that, we explain how the framework can be used to derive possible strategies during an upcoming and turbulent market around a radically new technological innovation. In general, the notion of a TIS framework has been criticized in several ways [14]. One of the limitations revolves around the lack of attention for company strategies. Innovation system frameworks traditionally focus on governments and are mostly meant to inform policy formation rather than strategy formation. We tackle this limitation by creating a TIS framework from a company perspective that is shaped to facilitate strategy formulation.

2.1. A general TIS framework to formulate strategies

The framework is built up in a few steps and is composed of seven building blocks and seven influencing factors [11]. Each of these building blocks is essential for the emergence of a complete market and for the large-scale diffusion of a technological innovation in that market. Conversely, in the case of absence, incompleteness or incompatibility of one or more of these building blocks, large-scale diffusion is seriously hampered. The building blocks are:

1. Product performance and quality;
2. Product price;
3. Production system;
4. Complementary products and services;
5. Network formation and coordination;
6. Customers;
7. Innovation-specific institutions.

The explanation of each of the building blocks is summarized in Appendix 1.

These building blocks are important to formulate strategies. If all building blocks are complete and compatible, then large-scale diffusion is possible. In that situation, companies may consider adopting large-scale production and marketing strategies to sell the innovation. In contrast, if none of the building blocks is in place, complete and compatible, then introduction strategies are not a realistic option. If some building blocks are incomplete or incompatible, then these building blocks represent barriers to large-scale diffusion. In such cases, companies can sometimes adopt specific niche strategies that circumvent the barriers. This means that analysis of the building blocks is important to decide about specific aspects of introduction strategies: the timing of introduction (early versus late) and the scale of introduction (niche versus large-scale introduction).

Timing and scale of introduction can be derived from the status of the building blocks and are important aspects of an introduction strategy, but do not suffice. Especially in the face of an emerging and incomplete market it is important to deliberately formulate a niche strategy that fits the situation. That means we need more information to formulate the type of niche introduction strategy. To do so it is important to explore the causes of the incomplete or incompatible building blocks. These causes, referred to as influencing factors, are:

1. Knowledge and awareness of technology;
2. Knowledge and awareness of application and market;
3. Natural, human and financial resources;
4. Competition;
5. Macro-economic and strategic aspects;
6. Socio-cultural aspects;
7. Accidents and events.

The explanation of each of the influencing factors is summarized in Appendix 2.

If combinations of the influencing factors and building blocks are systematically explored several niche introduction strategies come to the fore. All these niche introduction strategies can be found in practice, as can be illustrated by historical cases of technological innovations. Different types of such niche introduction strategies are outlined in Table 1.

Table 1: General niche introduction strategies [15,16]

Niche Strategies	Definition
Demo Experiment and Develop Niche Strategy	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 Strategy	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 when knowledge of the technology is lacking and it affects its price.
Subsidized Niche Strategy	Subsidize the product for a particular segment if its use is considered socially important, but it is too expensive for the target customer. Applicable when the product is too expensive for the market, or when resources are scarce.
Redesign Niche Strategy	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 Strategy	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 Strategy	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 Strategy	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 Strategy	Introduce the high-tech product where laws and rules are less strict, or where customers, suppliers and

Niche Strategies	Definition
	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 Strategy	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 Strategy	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.

3. Methods

Given the lack of specific literature about the innovation management aspect of autonomous shipping and the complexity of the maritime industry, we deemed exploratory research the most appropriate method for this article. So, we based our analysis mainly on qualitative data in the form of literature review and semi-structured interviews. However, to safeguard a broad empirical basis using these two qualitative approaches, we interviewed a wide variety of experts and practitioners, and we interviewed them in two rounds. In the first round of interviews, open questions were posed regarding relevant actors and factors and possible barriers to large-scale use of MASS. In the second round, after consolidating the list of actors and factors, we returned to the experts to have their verdict regarding the barriers among those actors and factors for the purpose of validation.

The present article was based on the same research method as Kurtinaitis Joukes [10]. Therefore, the method section of the present article is very similar to the method section in [10].

We started our research with a literature review. This was necessary 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. In this way, we came to understand the factors that prevent or encourage MASS large-scale adoption by the maritime industry. This literature review also allowed us to adapt the general list of barriers to the specific context of MASS. For this literature review we made use of textbooks, conference proceedings, white papers, and scientific articles available in the TU Delft Library database and on the internet. We used the keywords "Maritime", "Ships", "Autonomous"," Innovation", "Diffusion" and other similar terms in our search.

Because of the exploratory nature of this research, the broad variety of MASS usage in the maritime industry, the novelty of MASS technology and the lack of data regarding the barriers to its adoption by the maritime industry, next to the literature review we also made use of semi-structured interviews. The goal of semi-structured interviews is to have a specific set of questions for all interviewees but still allow room for further questions within the topic. This allows the interviewer to adapt the question list to fit the expertise of the particular interviewee [17]. We created a list of interview questions aimed at clarifying aspects of the literature available and acquiring more in-depth data about MASS and the TIS Framework actors and factors for the case of MASS.

3.1. Selection of interviewees

We performed 14 semi-structured interviews with MASS researchers, sailors, employees of companies that develop MASS technology, a ship owner, a Navy System Integrator involved in MASS projects and a shipyard manager. We chose these professionals based on their experience in MASS or their understanding of the maritime industry characteristics as shown in their LinkedIn profile, scientific articles or white papers written about the research topic. We contacted the interviewees using social media, or via the website of the companies for which they work. We asked each interviewee to refer to possible other interviewees, creating a snowball effect. The reason for choosing the only one of our interviewees not connected to the merchant marine sector, the Naval System Integrator, was not only 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 according to the diffusion scale defined by Rogers [18]. We made sure to have a broad variety of interviewees in terms of their background and expertise. However, all our interviewees were based in the Netherlands. That can be a shortcoming but the effect of this is probably limited because the maritime industry in the Netherlands is among the industrial clusters that is closely involved with MASS and all our interviewees had an international perspective.

3.2. Data Analysis

We recorded all interviews, except when the interviewee preferred not to be recorded. In this specific case, we used our interview notes as material for further analysis. We created an automated transcript of the recorded interviews by making use of the program Otter

AI, a program that transforms voice into text. After that, we reviewed the transcripts and interview notes according to the content and we assigned codes to different categories for further data analysis. A complete list of keywords and databases used in the literature review of this article, the list with all interview questions, an example summary of the interviews, and the table with codes and categories of the interview analysis are available upon request.

Both the data from the literature and data from the interviews are mainly qualitative and hence our analysis is also qualitative. We started with a generalizable TIS framework. We used a combination of qualitative data and well-informed opinions (also qualitative in nature) voiced by experts to adapt that framework to the specific maritime industrial context. After adapting the framework, we could qualitatively assess the main barriers. For some of the barriers, more detailed and quantitative data could have been gathered but that would not have resulted in a better comparison of the relative importance of these barriers. Neither would it form a better basis to select relevant niche introduction strategies.

4. Results

As presented in the Theory section, many breakthrough technologies require the presence of specific actors and factors, the so-called TIS building blocks. This section presents and explains the (f)actors affecting MASS specifically, based on our desk research and interviews.

4.1. RQ1: What is the status of the building blocks that together form a Technological Innovation System (TIS) around MASS and how is that status influenced by influencing factors?

4.1.1. Quality & Performance

Quality and performance are inherent to each product. For MASS, its quality is defined by its capacity to increase ships' performance in terms of reliability, efficiency, and predictability. These performance measures were mainly rated by our interviewees as very important. However, MASS has not yet proven its performance in all these aspects, rendering this building block partially present [10].

4.1.2. Cost-Benefit Ratio

The cost-benefit ratio for MASS is calculated in terms of return on investments (ROI), which interviewees believe can be achieved by crew reduction and/or and increased space for cargo because of MASS implementation onboard. Crew reduction is not (yet) regulated, making the business case for MASS adoption unclear to ship owners. Technology providers, on the other hand, ensure there is a valid return on investment to MASS, regardless of crew reduction. All interviewees considered cost-benefit ratio an extremely important building block. The Royal Dutch Navy interviewee is the only exception since the focus of the navy lies on reducing the number of crew members and less on costs. It is valid to note that navy vessels are not obligated to follow merchant marine regulations and therefore can determine their crew size based on their needs and not on legal requirements. Most interviewees agree that a beneficial cost-benefit ratio is still missing in the MASS TIS [10].

4.1.3. Production System

MASS is not expected to ever reach mass production, since ships are not built in the same numbers as cars. Our interviewees consider that a MASS production system is the capability to produce standardized items and have a set of hardware and software standards, regulated by accredited institutions. These standards do not exist yet, but the equipment is currently being built and sold. Therefore, this building block was considered present and moderately important [10], since the implementation of standards in the form of technology battles is common within technology development [19].

4.1.4. Network Formation & Coordination

When customers evaluate the value of a technology, they consider the perceived value of having a network that can or will increase the product's value in the future [20]. Our interviewees recognize there is little collaboration among companies offering MASS and the large ones create a closed loop of products, which shields smaller companies from a possible network. Knowledge is also not shared among companies offering MASS. Despite not being considered important, 'network formation and coordination' was recognized as a building block to MASS diffusion and deemed partially present [10].

4.1.5. Customers

The customers for MASS technology are ship owners willing to purchase and install the technology in their vessels. Without customers, there is no technology diffusion. Companies offering MASS claim to have sold and installed equipment; other companies mentioned potential customers and current clients interested in the technology. However, there is no widespread interest in the technology (yet). Hence, the building block is extremely important and only partially present [10].

4.1.6. Innovation Specific Institutions

MASS is not yet regulated by the International Maritime Organization (IMO), which means its conventions that regulate equipment and manning onboard vessels worldwide also do not address MASS. Most interviewees see this lack of regulation as a barrier to MASS diffusion. Given the strong weight of the IMO recognition of the technology and its impact on influencing factors described further in this section, this building block was evaluated as extremely important.

4.1.7. Safety

One interviewee described safety as a preconditional item that can only be increased onboard. From his perspective, every change on a vessel must increase safety, otherwise, it is not acceptable. All other interviewees and many researchers agree on this. This was the reason we decided to adapt the general list of TIS building blocks (see section 2) by including 'safety' as a separate building block. In other industries 'safety' may be seen as a kind of cost-benefit factor but in the maritime industry safety is a separate factor. What the interviewees cannot agree on is whether MASS will increase safety onboard or not [21-24]. The idea that MASS has the potential to reduce accidents onboard is widespread, still; few see this potential currently realized. Therefore, the building block is extremely important, but only partially present [10].

Summarizing the above analysis, we show the status of the TIS building blocks for MASS in Table 2 below.

Table 2: MASS Building blocks

MASS building blocks		
Quality & Performance	Very Important	🟠 Partially Present
Cost-Benefit Ratio	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

After the analysis of the building blocks, we further investigated the factors that influence the presence of these building blocks aiming at understanding the causes of the factors that currently influence the adoption of MASS.

4.1.8. Knowledge and awareness of technology

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 Collision Regulation (COLREG) rules issued by the IMO, are not yet grasped by AI systems, given it was made to be used by sailors. This opens room for interpretation. Communication difficulty between vessels and harbors or between conventional vessels and autonomous vessels was also pointed out by many interviewees as a difficult operational aspect to be solved. For lower levels of autonomy, where the crew is still onboard or when an operator is in the control room these aspects do not pose a problem, as the operator can correct possible AI mistakes. But it is an important influencing factor for unmanned autonomy. The lack of deep understanding of MASS technological principles is also a barrier to the regulators, who do not know enough about the advantages of disadvantages of the technology to regulate its use. This influencing factor is, then, partially hampering MASS adoption in the current MASS TIS [10].

4.1.9. Knowledge and awareness of application and market

Our interviewees noted that knowledge about the MASS application is a critical aspect, highlighting that even in the literature there are still misunderstandings about the difference between an autonomous and unmanned vessel, for example. Because of this reoccurring misunderstanding, many seafarers are afraid of being replaced by a machine. Ship owners are also not aware of how MASS can contribute to their operations. Most of the news about autonomous vessels is about unmanned autonomous projects, reinforcing the view that autonomous vessels are unmanned. Technology developers and researchers also lack knowledge about the maritime industry, disregarding the peculiarities of the industry such as its conservative thinking and the seafarers' knowledge as technology operators. Despite an increase in knowledge about MASS application in recent years, this influencing factor is still considered a partial barrier [10].

4.1.10. Natural, human, and financial resources

From the perspective of the ship owners, visualizing a good cost-benefit ratio is still difficult without the guarantee of crew reduction, and without this clear financial benefit, most companies do not want to have MASS only to increase safety. In this context, the problem seems to be the allocation of resources, rather than its availability.

The education of seafarers was also mentioned as a necessary aspect of MASS operation. 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 professional courses can be offered to increase the knowledge of officers after their graduation, as is currently done with Dynamic Positioning Officers.

The shortage of qualified seafarers [25,26] to operate the vessels is an encouraging factor for the development and adoption of MASS. Commercial vessels can enhance their profit margin, and the navy can maintain the vessels' operations even when there is little public interest in working for the military.

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. Both the availability of resources and the lack of qualified seafarers influence MASS adoption.

4.1.11. Competition

At the time of the data collection, not many companies we interviewed were working on MASS solutions and very few could offer a complete integration of maritime equipment and autonomy. This could be one of the reasons companies offering MASS solutions do not experience competition among themselves, but with the status quo, namely the conventional ships. MASS can make barge transport cheaper and more efficient, saving fuel costs and reducing waiting time, competing with truck transport. The current focus on CO_2 emissions challenges truck transportation and creates an ideal window to make this modal shift to barges. However, when trucks become electric, and later autonomous, barges will most likely have reduced commercial value.

Even though many international companies offer MASS solutions 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.

4.1.12. Macroeconomic and strategic aspects

The maritime industry was recently at the bottom of its ordering cycle, and it will go further up in the coming 10 years, so more ships are expected to be ordered and built in the near future. The decision of which technology to add to a newly built ship considers an operational asset life of 20 years, ideally with as few modifications as possible. The lack of regulations about MASS increases the financial risk of investment for ship owners, which is an important aspect of the low-profit-margin risk-averse maritime industry. The Dutch Navy has more flexibility regarding national and international regulations and is not pressured by profit margin, decreasing the risk of the investment. This is similar for navies in other countries. The ordering cycle stage and the reduced naval risks encourage both the military and the commercial vessels to invest in new technology. 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. Therefore, macroeconomic and strategic aspects represent an encouraging factor, only depending on the risk inclination of the investor.

4.1.13. Socio-cultural aspects

The maritime industry is not known for its openness to change; it is a conservative industry with a very strict task division on board. 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. Besides the overall fear of AI, many seafarers worry about their job and their safety, a social aspect of MASS that is also related to the knowledge and application of the technology. While society at large plays a role, ultimately the crew members are paramount to MASS acceptance; the crew operates the system, therefore if the members do not operate it correctly, the technology will not deliver its expected benefits. Benefits not delivered affect performance, which can affect adoption and stop (or delay) diffusion. Therefore, the socio-cultural influencing aspect is judged as a partially hampering factor.

4.1.14. Accidents and Events

National and international disasters and events have historically changed maritime regulations, such as the current international regulations which were developed after tragic accidents like the sinking of the Titanic, and the oil spill caused by the Exxon Valdez [27]. Accidents, however, are not unusual at sea; 65.8% of the accidents in the maritime industry are caused by human errors and MASS could decrease these numbers [28,29]. Despite not having one accident to name, the large number of accidents involving ships 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.

4.1.15. Complementary Products & Services

The Ortt & Kamp framework [11] introduces complementary products and services as a TIS building block, which is a factor capable of influencing the adoption of a breakthrough technology on its own. Complementary products & services for MASS were identified as reliable internet, a standard for data transfer and differentiated insurance policies for vessels equipped with MASS [10]. None of these, however, is seen by the interviewees as capable of affecting MASS adoption directly. Therefore, for MASS we consider them as influencing factors instead of a TIS building block. According to our interviewees, differentiated insurance policies, in the form of a complementary service, can influence the cost-benefit ratio, a building block that is paramount for the adoption and subsequent diffusion of MASS [10]. Data Transfer Standards and 100% internet coverage can also improve technical performance, influencing the quality & performance building block. Given its absence, Complementary Products and Services are a hampering influencing factor in the MASS TIS [10].

4.1.16. Operational Aspects

Operational aspects are not mentioned as influencing factors in Ortt & Kamp's framework [11] 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. These aspects 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 give maintenance to the engines, ensure cargo safety, communicate, and perform maneuvers to ensure the vessel's water tightness. Consequently, this factor does not have an immediate influence on MASS adoption, but it will have an effect later in the large-scale diffusion of MASS if/when vessels become operated by Remote Operation Centers (ROCs).

The status of the different influencing factors for MASS is shown in Table 3 below.

Table 3: MASS Building blocks

MASS Influencing Factors	
● Encouraging Factor ● Partial Barrier ● Barrier	
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	● (Barrier)
Operational Aspects	● (Barrier)
MASS Building Blocks	
● Present ● Partially present ● Absent	
Quality & Performance	● (Partially present)
Cost-Benefit	● (Absent)
Production System	● (Present)
Network formation & Coordination	● (Partially present)
Customers	● (Partially present)
Innovation Specific Institutions	● (Partially present)
Safety	● (Partially present)

4.2. RQ2: How can potential (niche introduction) strategies be derived from the analysis of the TIS around MASS?

Now that we have knowledge of the status of the different TIS building blocks for MASS and how the influencing factors influence that status, we can derive niche strategies for the introduction of MASS in the market. The logic here is that the niche strategies are specifically derived to address incomplete or partially complete TIS building blocks in combination with their influencing factors.

4.2.1. Quality & Performance

The main issue with MASS lies in the fact that the technology is not yet proven. Little is known about commercial tests as companies only share Public Relations articles when they have positive outcomes. Most interviewees indicated that they did not know much about how MASS works.

Demonstrating, however, is not impossible and it was suggested by crew members interviewed as a way to prove MASS can deliver what it promises. The Demo experiment and Develop Niche strategy, explained in the theory section, suggests a similar approach. In this 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 the awareness of the public [15]

Given the nature of MASS, it needs a demonstration that can be followed at a distance, like the blog created by the Mayflower developers [30] where it was possible to follow the vessel online, demonstrating its capabilities on a daily basis. Such live demonstrations can enhance trust in the system's capabilities. As a by-product, such online activity might also improve 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.

4.2.2. Cost-Benefit Ratio

One point was very clear for most interviewees: If the MASS suppliers want to sell, they need to present a clear business case and therefore a positive cost-benefit ratio. From the perspective of the companies offering technology, regulations must recognize MASS and allow crew reduction. If crew reduction is approved, the decision to adopt MASS becomes clear-cut for ship owners. IMO is working on a MASS code, with the non-mandatory part expected to be ready in 2025 and the mandatory code to enter force in 2032. Two strategies that can be used to overcome the cost-benefit ratio barrier, both described in the theory section [15]. The first one is the Top Niche strategy, which aims at a market segment that is not constrained by the price of the technology. The Royal Dutch Navy is more interested in crew reduction than in cost-benefit ratio and it does not have the obligation to comply with international rules regarding crewing [10]. Therefore, it is a suitable option for the Top Niche strategy. According to our interviewees, another maritime market segment known for its lack of budget constraints is the leisure yacht market segment, 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 combining the new product with the old version [15]. A similar strategy is being pursued by two companies interviewed. Both offer MASS to existing vessels, while one ensures it sells a product and not a project, offering installation in every ship. The other focuses on retrofitting or installing the equipment in existing and operating vessels. Currently, the second company offers operational visibility to ship owners, not autonomy. The equipment installed, however, will learn with the vessel and, in the future, the company intends to add autonomy to the already sold product. The approach used by the second company resembles a combination of the previously mentioned Hybridization Niche Strategy with the Lead User Niche Strategy, which is explained is as a partnership with users that are willing to co-develop and experiment with technology [15].

4.2.3. Network Formation & Coordination

According to our interviewees, there is little collaboration between MASS providers and the network of complementary services, which directly affects the knowledge of the technology and its application. Interestingly, our interviewees understand the network as the exchange of information and ideas between the industry and its players. In the MASS context, a university of technology 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 network formation for MASS. In general, research institutes can play an important coordinating and even leading role in the initial stages of development and diffusion of a radically new technology (e.g., [31])

4.2.4. 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 [11]. We found that potential customers lack awareness of MASS competencies, which affects their interest in purchasing and installing the technology in their vessels. To increase customers' interest, companies offering MASS solutions need to educate their market.

The Educate Niche Strategy is recommended to ensure customers have a better understanding of the technology [15]. The authors suggest organizing conferences and closing partnerships with universities to enhance the knowledge and awareness of innovative technologies. Organizing conferences can be rather costly to companies struggling with financial resources, and this is the situation for 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 vessel programs funded by national governments and institutions. Participation in these projects can have a twofold contribution to MASS adoption. On the one hand, smaller companies can piggyback on the resources of national programs to enhance awareness about their product. On the other hand, the participation of informational intermediaries, the universities and the joint industry projects, facilitates the network formation for MASS. Therefore, adopting the Educate Niche Strategy can help the companies solve the Customers' barrier to MASS adoption and diffusion.

4.2.5. Innovation Specific Institutions

Institutions, more specifically regulations regarding the number of crew members onboard, pose a large barrier to MASS adoption. The uncertainty about crew reduction possibilities hampers the adoption of MASS, except for military applications. Therefore, changes in regulations can have a substantial influence on MASS diffusion.

The Geographic Niche strategy is proposed when breakthrough technologies are restricted by regulations, suggesting introducing the technology in areas with more flexible rules [15]. 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 [32], companies offering MASS can request a Minimum Safe Manning 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 [23] than waiting for an IMO international recognition.

4.2.6. Safety

Safety is not a building block encompassed by the Ortt & Kamp framework [11], although it is paramount to MASS adoption [10]. Therefore, there is no entry strategy presented in our theory section designed to ensure the safety of a product in its market introduction.

Wróbel, Montewka, & Kujala [25] highlight the complexity of proving safety. Safety can be proven in different ways, for example by meeting requirements, by testing designs or by measuring actual accidents after implementation. All these ways have their shortcomings and are incomplete in terms of ensuring safety. According to Ventikos, Chmurski, & Louzis [33] the autonomous shipping systems should mimic human logic and actions in their decisions. For example, when an autonomous ship gives way to another ship, the maneuver should be clear and visible, rather than only optimal. Although helpful, the authors' suggestion does not influence MASS adoption because the input of humans in the AI decision-making process is not visible to crew members and ship owners that will operate and buy the technology respectively. Therefore, this study cannot propose a useful strategy yet to address safety concerns. The table with the main strategies that we found for the main barriers is shown in Table 4 below.

Table 3: Strategies to Surmount MASS Barriers

Strategies to Surmount MASS Barriers		
⚫ Present	🟠 Partially Present	🔴 Absent
Quality & Performance	🟠	Digital Demo experiment and Develop Niche Strategy.
Cost-Benefit Ratio	🔴	Top Niche Strategy.
		Hybridization Niche Strategy
		Lead User Niche Strategy
Production System	⚫	
Network formation & Coordination	🟠	Build relationships with institutes researching MASS
Customers	🟠	Educate Niche Strategy
Innovation Specific Institutions	🟠	Geographic Niche Strategy
Safety	🟠	… (No strategy defined yet)

5. Discussion

In this article, we focus on MASS and in order to illustrate how to analyze the wider system around a radically new technological innovation. This analysis allows us to explore an upcoming market and derive introduction strategies into that market.

5.1. Answers to the research questions

Our first research question is 'What is the status of the building blocks that together form a Technological Innovation System (TIS) around MASS and how is that status affected by influencing factors?'. Our analysis revealed that the main barrier for MASS is the lack of cost-benefits, or a lacking viable business model to apply MASS. Other building blocks are partly complete except for the production system for MASS technology, which was found to be ready and complete. So, only one building block of the TIS is considered complete and all the other ones are incomplete. That means that the TIS analysis reveals that MASS is not even close to the start of large-scale diffusion. Similarly, several influencing factors were found to have a negative effect, among which are operational aspects and a lack of complementary products and services. The status of the influencing factors confirms the idea that MASS will not start to diffuse on a large scale soon, as also shown in [34].

Our second research question is 'How can potential (niche introduction) strategies be derived from the analysis of the TIS around MASS?'. The strategies presented in this article show different ways to deal with each incomplete or absent building block in the MASS TIS. Depending on the influencing factor that is found to be the cause of the incomplete building block, different niche strategies can be adopted. The lack of quality and performance of the technology and the lack of knowledge of how to apply the technology in practice, for example, can both be improved with a Demo Experiment and Develop Niche strategy. In this niche strategy, the technology developers demonstrate the product in a controlled environment to further develop it and learn to use it and at the same time it enhances the awareness of the public [15]. The biggest barrier for MASS turned out to be the lack of a good business model, referred to as the cost-benefit ratio barrier. Two strategies are suggested to overcome the cost-benefit ratio barrier. The first one is the Top Niche strategy, which aims at a market segment that is not constrained by the price of the technology. An example of a niche segment in which this strategy may work is the Royal Dutch Navy, which is more interested in crew reduction than in financial costs. Another segment in which this strategy may apply is the high-end leisure yacht market segment. The second strategy to overcome the cost-benefit barrier is the Hybridization Niche Strategy, which entails making the new product compatible with existing complementary services or combining the new product with the old version. In a similar way, several other specific niche introduction strategies are suggested to deal with incomplete building blocks, or barriers in the market.

5.2. Contributions

The article contributes to the scientific domain of TIS in several ways. Firstly, the article presents an adapted TIS framework, specifically reflecting the industrial context of international cargo shipping. This focuses attention on the notion that a general framework needs to be modified for the context in which it is used. We also found several such modifications necessary in studies adapting the same general TIS to other industrial contexts (e.g., [35-36]). One of the adaptations made to the TIS framework in this article is that in the MASS, safety is considered a building block instead of an influencing factor. We found it to be affected by the influencing factors accidents and events, knowledge and awareness of the technology and socio-cultural aspects. With regard to strategy for this building block, it is possible to infer that a strategy to overcome the safety barrier must include measures related to the influencing factors accidents and events, socio-cultural aspects (the norms and values of behaviors at sea) and awareness of the technology. However, this study has not found any suitable strategies yet to overcome this barrier.

Secondly, another way to reflect the intricacies of a particular context is to indicate how important each TIS building block's status is. In this article, this has been done for the first time in a TIS-analysis. Building blocks represent aspects that generally, across a wide range of industrial and geographic contexts, are important for large-scale diffusion of a technological innovation. However, depending on the geographic or industrial context, their importance may vary considerably. In the case of MASS we found that the only complete building block was considered just moderately important, for example. In contrast, the building block that was fully incomplete, however, was considered extremely important by interviewees. This extra analysis in more detail confirms the overall conclusion that MASS is far from large-scale diffusion.

The article also represents managerial and societal contributions. The framework is a kind of dashboard that, when tracked carefully over time, indicates when MASS may begin to diffuse on a large scale. That is an important managerial instrument because it allows companies to prepare for upcoming large-scale diffusion. Conversely, the framework can also prevent unnecessary preparation for introducing or adopting MASS when the conditions for large-scale diffusion are simply not met by far. Societally, the analysis using the TIS framework can help governments and companies to address barriers, remove them and hence speed up the development and start of large-scale diffusion.

5.3. Limitations

The first limitation is that the research is time-constrained and in view of the speed of development of improved technological systems, the results can be outdated within a few years. On the other hand, some radically new technologies seem to remain in a status that is considered to be "just before large-scale diffusion" for decades. Inevitably the analysis needs to be updated in the future to explore whether the status of building blocks and influencing factors have changed. As a result of such changes, new niche introduction strategies may need to be considered.

A second limitation is that interviewees came from one country, the Netherlands. The reason is that we had access to the experts, researchers and practitioners in this country. The effect of this limitation may be limited because all interviewees showed themselves to have an international perspective.

The TIS framework considers the building blocks as separate, independent aspects. That is a third limitation. Actors and factors in a TIS are interrelated, which means that adopting a strategy to deal with a barrier might create a new barrier and hence the strategy may not have the desired effect. An example can be taken from the cost-benefit ratio building block and the Top Niche Strategy. 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 market segments are only a small percentage of the maritime sector. The strategy would be minimizing the importance of the customers, safety and institutions, all deemed to be also extremely important in the MASS TIS. Since many factors are considered extremely important, a pathway addressing them simultaneously has a higher probability of success on the road to MASS diffusion.

5.4. Future research

In future research a wider set of interviewees, from across different countries, can be approached. This may reveal different conditions in different regions, and how these conditions call for different niche introduction strategies.

We used qualitative data and analysis methods. In future work it may be useful to track the changes of the building blocks and influencing factors over time. That may call for a quantification of measuring these building blocks and influencing factors. Using the current qualitative approach, we could only explain why a building block changes from red (a complete barrier) to orange or green (no barrier). Such a crude and qualitative assessment may suffice to reflect a current condition and choose a niche introduction strategy but will not suffice to carefully track changes over time.

Then there is the issue of safety concerns. As this building block was newly added to the TIS framework in this study, there is no suitable niche strategy yet to address this. This is another interesting topic for future research.

The interrelation of actors and factors in a TIS calls for more advanced models taking all the building blocks and influencing factors into account. The current TIS analysis represents an overview that reflects conditions at one point in time and ignores possible interactions. This suffices to select possible niche introduction strategies that fit these conditions. Inevitably the analysis using the TIS framework needs to be repeated over time to reflect changes in the conditions. If interrelationships are taken into account, then more dynamic models could be developed that also capture the causes of changes over time. Studying the development and diffusion of radically new technological innovations, it becomes clear how fascinating the dynamics in these processes can be.

6. Conclusion

Large-scale application of Maritime Autonomous Surface Ships (MASS), being a radically new technological innovation, is still hampered by several barriers. In this paper we have applied the TIS framework to identify the main barriers and their causes and to formulate niche strategies. The main barriers include the cost-benefit ratio, safety issues and quality and performance. Niche strategies such as the Top Niche Strategy can be used to introduce MASS in niche markets first, for example the navy. This could be a first step towards the introduction of this technology on a large scale.

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7. Appendices

7.1. Appendix 1: Descriptions of the TIS building blocks

Building Blocks	Description
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 the 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 the 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 facilitates the TIS formation.

7.2. Appendix 2: Descriptions of the influencing factors

Influencing Factors	Description
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 Application and Market	The price of a product involves not only its m This influencing factor 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 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 resources 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 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. 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 macroeconomic conditions, such as the market structure, making both macroeconomic 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 behavior of TIS actors, such as safety concerns. 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.