A system's perspective analysis of barriers to MASS large-scale diffusion

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Abstract— This article analyses current developments in Autonomous Shipping (MASS) by adopting a socio-technical system perspective to explain why the technology is (still) only applied in small-scale niche applications and still not applied on a large scale. Using literature study and an exploratory research approach to obtain in-depth information from naval practitioners and experts in the (autonomous) shipping industry we identify which factors currently stimulate or hamper the diffusion of autonomous shipping.

An analysis of the Technological Innovation System (TIS) of the maritime industry shows that the 'standard' building blocks framework requires adjustment with regard to the market building block to makeit applicable to analyze and understand developments in and motives and drivers of Autonomous Shipping. A subsequentanalysis of the current status of the maritime-specific market building blocks showed these were to a large extent complete, with the exception of cost-benefit aspects. This result shows that large-scale diffusion is primarily hampered by this issueand cannot easily be resolved in the foreseeable future.

Keywords— *MASS, Autonomous shipping, innovation, Market, Barriers*

I. INTRODUCTION

Historically, the maritime industry seems to lag in the adoption of new technologies as compared to the aerospace industry. The "Blackbox" and AIS, for example, are technologies that were adopted in the aerospace industry decades before they were adopted in the maritime industry. The adoption of autonomous technology is not different. Clearly, the maritime industry seems to lag in comparison to the aerospace industry.

The current article evaluates Autonomous Shipping (MASS) by adopting a socio-technical system perspective. We will consider the Technological Innovation System (TIS) of the maritime industry to understand what aspects determine the current adoption rates of autonomous technology in that industry. The goal is to explain why the technology is only applied in small-scale niche applications and still not applied on a large scale. Such a TIS can explain the adoption rates in the maritime industry, asl well elucidate why particular market niches within industries are relatively earlyor late in adopting a technology. Why were military jets, for example, outfitted with autonomous technology relatively early compared to and trucks and cargo ships in their respective industries?

Comparing the status of development and diffusion of technologies across industries requires a kind of process over time with subsequent phases. We use a pattern of development and diffusion with three phases [1] [2]. The pattern is defined in terms of three hallmarks: invention, first introduction, and start of large-scale production and diffusion. Using these hallmarks three phases can be distinguished: the innovation phase (between invention and first introduction), the adaptation phase (between first introduction and the start of large-scale production and diffusion), and the stabilization phase (after the start of large-scale production and diffusion) See Figure 1.

To assess the status of a technology, it is important to carefully define the technology. In our previous article we defined MASS as: "Autonomous shipping means that a ship can navigate autonomously (meaning it needs no human intervention, either onboard the ship or elsewhere, to perform specific navigational tasks) by applying the technological principle of Artificial Intelligence and integrating that principle with subsystems to monitor the environment of the ship, its course and speed, as well its internal functioning, so the ship can adapt its navigation to reach an intended position." [3]. After analyzing relevant data, we concluded that MASS is in the adaptation phase. That means that MASS is currently applied in small-scale, specific market niches [3]. That inspired us to focus on the following research questions:

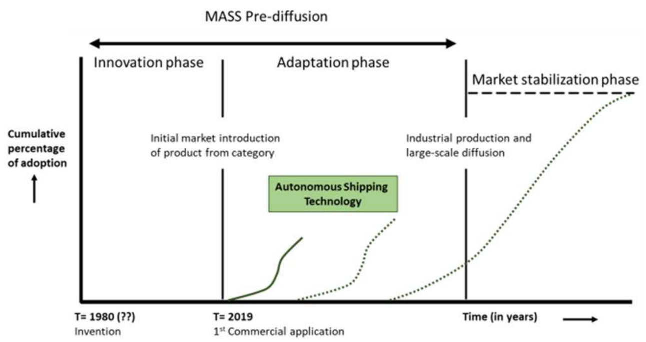

Fig. 1. *The status of Autonomous shipping in the pattern of development and diffusion.*

RQ1. What is needed in the market, in terms of social and technical factors, to enable large-scale diffusion of MASS?

RQ2. What social or technical factors currently encourage/ hamper the diffusion of MASS?

RQ3. What are reasons to consider adoption of MASS in the maritime industry?

The first question focuses on different conditions, be it social or technical, required for large-scale diffusion of autonomous technology in the maritime industry. We will consider these conditions as building blocks, that together form a market system. The second question explores those incomplete building blocks in the market that currently hamper large-scale diffusion of autonomous shipping in the maritime industry, and thus represent barriers to large-scale diffusion. The third question focuses on motives or drivers to consider adoption and thus to further develop and then implement and apply autonomous technology in the maritime industry.

In the next section we will present the theory by explaining the main building blocks of a market. The third section will explain the methodology. The fourth section will present the maritime market and the conditions within the market that are hampering large-scale diffusion. Conclusion and discussion are in the fifth section.

II. Theory

It is important to realize that large-scale diffusion is not the only possible outcome of the further development and diffusion of Autonomous Shipping technology. It might be that MASS is only useful in specific market niches, even in the long term. Or it might be that MASS will completely disappear after the first applications in specific market niches. We need to define a market environment in terms of actors and factors that may hamper such large-scale diffusion in order to indicate why the MASS technology is not diffusing on a large scale.

Over time, different market definitions have been proposed in economics and management science. In some cases, markets are primarily defined in terms of (potential) customers i.e., in terms of their demand-side alone. Such a demand-side perspective can be found in diffusion literature, for example [4] but also in parts of the management literature [5] [6]. From a (company) management perspective, however, the market consists of various actors, both on the supply and the demand side of the market. Furthermore, markets include other actors with a direct impact on demand and supply. From this perspective, the market around the company includes network partners, customers and supporting institutions, all of which are important in market formation and need to be considered when formulation commercialization strategies. Following this line of reasoning we take a system's perspective on markets around technological innovations and define seven building blocks that together make up a market [7] (see Ortt & Kamp, 2022 for a full derivation of the building blocks).

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. Or to put it differently, these building blocks represent necessary conditions for large-scale diffusion. 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.

TABLE I. TIS Building Blocks

Actors/ Factors	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 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 customers have reasons to adopt the innovation. 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.

We will study whether these building blocks apply in the maritime industry or not. The (modified) set of building blocks answer RQ1. The status of the market building blocks for Autonomous Shipping technology answer RQ2. To answer RQ3 (What are the reasons to consider adoption of AS in the maritime industry?) we will focus on the reasons why potential customers might consider adoption of MASS. That means that the third research question zooms in on one of the market building blocks, notably 'customers'.

III. Methods

Given the lack of specific literature about the innovation management aspect of autonomous shipping and the complexity of the maritime industry, we conducted a exploratory research. This article thus relies primarily on qualitative data available via literature, and additional data was obtained through semi-structured interviews.

The literature review of this article aims to understand potential reasons to adopt autonomous shipping, as well as the barriers to MASS technology development. Our goal is to identify the factors that either prevent or encourage MASS large-scale adoption by the maritime industry. For the literature review, we used textbooks, conference proceedings, white papers, scientific articles available at the TU Delft Library database and on the internet, as well as websites of MASS companies and initiatives using the keywords “Maritime”, “Ships”, “Autonomous”,” Innovation” and “Diffusion” and their synonyms.

Because of the exploratory nature of this research, the broad possibility for 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, we deemed the use of semi-structured interviews necessary. The goal of this data collection method is to pose a specific set of questions to interviewees but allow room for explanation and exploration within the topic. This allows the interviewer to adapt the interview to fit the expertise of the interviewee [8]. We created a list of questions aimed at clarifying aspects of the literature available and acquiring more in-depth data about the MASS topic and the Building Blocks Framework actors and factors.

A. Selection of Interviewees

We held the semi-structured interviews with MASS researchers, sailors, employees of companies developing MASS technology, a shipowner, a Navy System Integrator involved in MASS projects and a shipyard manager. These professionals were selected 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 other possible interviewees, creating a snowball effect. 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 [9].

B. Data Analysis

All interviews were recorded, and an automated transcript was generated by Otter AI, a program that transforms voice into text, except when the interviewee preferred not to be recorded. In this specific case, the notes of the interview served as material for further analysis. The transcripts and notes were reviewed according to the content and codes were assigned to different categories for further data analysis.

A complete list of keywords and database used in the literature review of this article, the list with all questions, an example summary of the interviews, as well as the table with codes and categories of the interview analysis is available upon request.

IV. RESULTS

A. What is needed in the market, in terms of social and technical factors, to enable large-scale diffusion of MASS?

As presented in the Theory section, many breakthrough technologies require the presence of determined actors and factors. This section presents and explains the (f)actors affecting MASS specifically, according to interviewees that are industry professionals, researchers or companies developing MASS solutions.

- Quality & Performance

According to our interviewees, voyage efficiency, particularly the use of fuel, CO2 and NOx emissions, predictability and reliability are performance indicators for maritime equipment. Environmental friendliness is considered slightly important for MASS, as the technology contribution to emission reduction is minimal when compared to the substitution of diesel engines by other propulsion methods. MASS vendors claim that the technology increases voyage efficiency by using current streams and maintaining the ideal distance from river margins. It also reduces fuel usage by sailing at constant speed, and has data indications of reduced emissions. These performance improvements however, were not yet statistically proven when the results of this research were collected.

- Cost-Benefit

TIS Building Blocks considers price as influencing factor of large-scale diffusion. The interviews pointed that cost benefit, which is the financial return associated with the equipment purchase, is considered more important than the price in the industry. According to interviewees, Cost benefit for MASS is measured in terms of Return on Investment (ROI), crew reduction, fuel savings and increased cargo space. For most interviewees, the MASS ROI is only attainable with crew reduction, given the magnitude of the installation costs. Companies offering MASS solutions, however, sustain in their claims that investing in autonomy is profitable in terms of ROI and can be achieved without reductions in manning.

- Production System

The Production System of ships and shipping equipment is not comparable to cars, where thousands of products are mass produced weekly. Therefore, MASS production system is not expected to shift to mass production, even if the technology is fully diffused. Within the perspective of maritime industry, however, the MASS production system is still producing single items, and not yet characterized as standardized. It was also pointed out by one interviewee that there are no standards for software and hardware for MASS solutions, showing that the production system still needs standardization in terms of certification and legislation to ensure appropriate quality and interoperability in different geographical areas.

- Network Formation & Coordination

In the theory we describe network as companies that can supply parts and provide complimentary services that will increase the added value of a technology. One interviewee included the collaboration among MASS providers in the perspective of network formation and collaboration. In his view, the benefits reaped from sharing experiences among technology providers is also important for MASS diffusion.

This comment was focused, at the time of the interviews, on larger companies developing MASS solutions kept a close loop of complementary products aimed only at their own equipment, making it very expensive for smaller companies to offer a good ROI to their customers.

- Customers

Without customers there is no diffusion and MASS customers are mainly the shipowners who expect a return on their investment. Our interviewees offering MASS solutions mentioned customers had an overall awareness about MASS without deep understanding, but not many actual purchases. Most purchases focused on survey vessels, or insight into performance which would be later upgraded to autonomy. The shipowner interviewed mentioned interest in the technology, if there was a guaranteed ROI, which could not be foreseen to his company without crew reduction.

- Innovation Specific Institutions

Innovation specific institutions, as mentioned in the Theory section, include formal rules, government policies required for the TIS formation, as well as research institutions focused on innovating. The maritime industry is regulated by the International Maritime Organization (IMO) and regulations defined by this body and the international convention for Standards of Training, Certification and Watchkeeping (STCW) which has kept the vessels safe for the past decades, but they are becoming less relevant with the current level of automation [10]. There were no clear standard regulations regarding the use of MASS by IMO at the time of data collection. On the innovation institutions, there are many initiatives, some with national governments involved, focused on research and development of MASS, at the example of SMASH in The Netherlands [11], ONE SEA in Finland [12], ShippingLab in Denmark [13] and AUTSHIP for European Waters [14].

- Safety

Safety is not a building block defined by the Building Block framework; thus, it was not defined in the factors affecting diffusion detailed in the Theory section. However, safety was mentioned by all interviewees as building block for MASS adoption. Safety for MASS is divided into two aspects: Accident reduction, and cyber security. The cyber security aspect, brings the fear of vessels being hacked and used with ill intentions, which could be increased by the adoption of MASS. This concern, according to our interviewees, is not different than any other technology connected to the Internet and can be overcome by timely security updates, not affecting MASS adoption particularly.

Accidents, however, are a great concern of the maritime industry which will be further detailed in the answer to RQ3. According to interviewees, safety is preconditional and it can only be increased. Every change on a vessel must increase safety, otherwise it is simply not acceptable. On this perspective, there is an overall agreement among practitioners that MASS has the potential to reduce accidents and that safety is a driver to adopt MASS. However, the promise of safer vessels is not yet proven, as proving safety is proving the absence of accidents, which is not easily done [15].

- Complimentary Products and Services

The compiled list of MASS social technical factors that enable large-scale diffusion does not include Complimentary Products and services as a factor to MASS diffusion because the interviewees did not consider this factor as important for adoption. For MASS, interviewees considered reliable internet, standard for data transfer and differentiated insurance policies for vessels equipped with MASS as complementary products and services. Nonetheless, their presence was not thought to affect MASS adoption. The differentiated insurance policies could affect the cost-benefit, but on its own it would not be enough to hamper or encourage MASS adoption.

B. *What social or technical factors currently encourage/ hamper the diffusion of MASS?*

The answer to this research question builds on RQ1 answer above by adding the evaluation of the interviewees regarding the presence and importance of the actors and factors affecting enabling MASS large-scale diffusion. As it was stated that Complimentary Products and Services do not directly affect large-scale diffusion, this building block is mentioned in this section.

- Quality & Performance

Overall, the factor Quality & Performance was considered very important by the interviewees and partially present, given that reliability and predictability of MASS solutions were not yet guaranteed at the time of the data collection. Given its partial presence, this factor partially hampers the diffusion of MASS.

- Cost-Benefit

Cost-benefit was deemed extremely important by all interviewees, except for the Navy interviewee, who claimed that, for the Royal Dutch Navy, crew reduction is more important than the ROI associated to it. Given the nature of naval vessels activities and the shortage in Navy personnel, this specific niche of the market considered cost-benefit as slightly important. On the presence of this factor in the MASS TIS, most interviewees deemed it absent, hampering MASS adoption. This highlights that shipping companies cannot yet see the ROI of MASS adoption if crew reduction is not allowed by maritime regulation, as it was discussed further in the answer of RQ1.

- Production System

MASS is not expected to be diffused as large-scale consumer technology, because of the nature of the industry and price of its assets. The interviewees regarded this factor as moderately important and fully present, as there are already MASS solutions in the market, and these can be delivered as the customer purchases them. Production system therefore, encourages MASS diffusion.

- Network formation & Coordination

Interviewees acknowledged the partial presence of the Network formation & Coordination as factor to MASS large-scale diffusion. But they did not highlight its importance in the TIS. Therefore we categorized it as slightly important. Thus, this factor partially hampers MASS diffusion.

- Customers

There are companies currently offering MASS solutions to different branches and it is commercially available for survey vessels. However, few customers see MASS as a valuable solution. Therefore, this building block was categorized as extremely important, but only partially present by the interviewees, hence partially hampering MASS diffusion.

- Innovation Specific Institutions

Maritime regulations were considered an extremely important factor acting as a barrier to diffusion for all interviewees, except the Navy interviewee, whose vessels do not fall under STCW regulations. For all commercial parties, the lack of regulations brings uncertainties to whether MASS is good enough to be accepted by IMO. As mentioned before, the majority believes the cost-benefit of MASS can only be achieved with crew reduction and the legislation uncertainty also generates ROI uncertainty to shipowners. Given the presence of the research related institutions, the institutional aspect is perceived partially present, but its extreme importance makes it a barrier, consequently hampering MASS diffusion.

- Safety

Despite not being a Building Block defined in the generic building blocks framework, Safety is considered extremely important for the maritime industry. As the safety improvement by adoption of MASS, cannot easily be proven without adoption, this factor was considered partially present by the interviewees. Safety thus acts as a partial hampering factor to MASS adoption.

TABLE II. ADAPTATION OF BUILDING BLOCKS FRAMEWORK

Actors/ Factors	Importance	Presence
Quality & Performance	Very Important	Partial Barrier
Cost-Benefit	Extremely Important	Barrier
Production System	Moderately Important	Encouraging
Network formation & Coordination	Slightly Important	Partial Barrier
Customers	Extremely Important	Partial Barrier
Innovation Specific Institutions	Extremely Important	Partial Barrier
Safety	Extremely Important	Barrier

C. *What are reasons to consider adoption of MASS in the maritime industry?*

Vagale et al. state that the MASS market is expected to experience rapid growth 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 revenues of nearly 3.5 billion USD by 2035. Among the reasons behind such a positive outlook, the authors mention a list of potential advantages of MASS, which include human error reduction; increase in performance and reliability; enhanced controllability and flexibility; reduced costs and improved safety; as well as increased space for cargo [16]. The above-mentioned advantages can be found among numerous autonomous shipping projects' goals, at the example of the already mentioned ONE SEA, AUTOSHIP, SMASH and ShippingLab.

Below we discuss in detail the 2 categories that comprehend most, if not all the reasons for adopting MASS.

- Safety

MASS has the valuable 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 [17]. 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 [18].

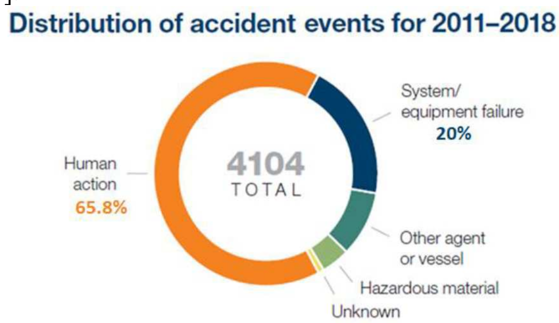

Fig. 1. Distribution of Maritime Accidents 2011-2018. (*Wärtsilä,221*)

Wróbel, Montewka, & Kujala analyzed 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 [15]. This view is aligned with the results of the interview conducted with seafarers by the Nautilus Federation, an association of shipping and inland water ways. In the report, 85% of the interviewed seafarers argue that MASS is a threat to safety at sea because their presence onboard avoids that simple failures, such as leaking pipes, escalate to large accidents [19].

On a further specified research, Ventikos, Chmurski, & Louzis [20] evaluated the level of hazards based on the level of autonomy achieved by the vessel. Their study shows that increasing autonomy levels, also increase the possibility of applying mitigation measures attempting to eliminate hazards and losses. The authors 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.

This academic research is aligned with the interviewees, while it shows the MASS potential to increase safety, but does not see that as given and still lacks proof that MASS adoption will, undoubtfully, increase safety onboard.

- Economic considerations

Kobyliński argues 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. The author adds that more potential cost reduction could be achieved with savings in fuel consumption due to optimal speed [21]. These assumptions do not consider the many other functions performed by the crew aside from navigational duties. Bertram [22] disagrees with this perspective explaining that the costs incurred by installing all MASS equipment might add more costs than what is saved by removing the crew.

Kooij [23] presents the issues of the crew tasks beyond navigation that are not (yet) simply automated. She explains that a solution to reduce a crew from 12 to 3 members would reduce crew costs in 50%, but it would also increase the workload of the remaining seafarers and changing the nature of the task performed by the remaining crew members. This change would pose a barrier, given the conservative nature of the maritime industry to new work systems [22].

In the economic aspect, the interviewees have similar perspective that MASS cost-benefit is not straightforward, as mentioned in the cost-benefit section. This view is aggravated by the lack of regulation allowing crew reduction, which would ensure business case for implementing MASS.

V. CONCLUSION

In the article, we focus on three research questions. The first question revolves around different conditions, be it social or technical, required for large-scale diffusion of autonomous technology in the maritime industry. The second question explores those conditions, referred to as market building blocks, and assesses which ones currently hamper large-scale diffusion of autonomous shipping in the maritime industry. The status of these building blocks thus represents barriers to large-scale diffusion. The third question focuses on motives or drivers to consider adoption of autonomous technology in the maritime industry.

Our interviews scheduled with various stakeholders in the maritime industry to answer the first research question revealed that most of the market building blocks as envisioned by Ortt & Kamp [7] in their generic TIS-framework are also applicable in the maritime industry. We found two notable differences. Firstly, safety was of paramount importance and hence added as an extra market building block. Secondly, complementary products and services were perceived as an unnecessary part of the maritime TIS. That means that we formed a maritime specific set of market building blocks, consisting of the following aspects: Quality & performance aspects, cost-benefit aspects, availability of a production system, network formation of actors and coordination of these actors, customers, innovation specific institutions, and safety aspects.

Our subsequent analysis of the status of these maritime-specific market building blocks (answering the second research question) showed that all these building blocks were partly complete, except for the availability of a production system (which is considered complete and hence does not hamper large-scale diffusion) and cost-benefit aspects (which are not even partly complete and hence block large-scale diffusion). This result not only shows that large-scale diffusion is not yet possible, but it also shows that this will most likely not be the case soon. That is in sharp contrast to some sources like Vagale et al. [16] who claim that the MASS market will start growing with double-digit numbers from 2024 onwards.

This result opens two avenues for future research. Firstly, future research can focus on assessing or predicting when all market blocks are in place for large-scale diffusion. This could possibly be done by referring to a set of influencing conditions that affect the status of the market building blocks. Ortt and Kamp [7] formulated a set of such influencing conditions but they did not specify how to use these conditions to predict changes in market building blocks. Secondly, it is possible to introduce technological innovations in a market even before all market building blocks are in place. In that case specific niche strategies may be adopted instead of large-scale introduction strategies [7].

Future work may focus on formulating possible niche strategies for MASS in the maritime industry. The interview and literature review results pertaining to our third research question (What are reasons to consider adoption of MASS in the maritime industry?) further indicate why large-scale diffusion might be hampered for a while. We found two motives that stand out. Firstly, safety is one of the most important reasons to consider adoption. Our analysis reveals that in some situations, autonomous shipping might increase safety (it might reduce navigational errors by humans), whereas in other cases it might decrease safety (when flexible human behavior compensates system errors). The changes that come with autonomous shipping call for fundamental changes in regulations, and that is a time-consuming activity for governance bodies which develop rules and guidelines for world-wide international waters. Secondly, financial considerations indicate that autonomous shipping does not decrease costs significantly when crew members need to be onboard for other tasks than navigation. The cost savings are more modest than expected and the changes that come with the implementation of autonomous shipping will most certainly transform job descriptions, roles and routines of crew members and hence are bound to meet stiff resistance.

This result opens an interesting avenue for future research. How can the full navigational system for cargo ships be redesigned to benefit from the characteristics of autonomous shipping? Just making the current cargo fleet navigating autonomously does not lead to significant reductions unless harbor configurations, sea routes and oversight are redesigned and unless crew member functions and job descriptions are fully revised.

VI. THEORETICAL CONTRIBUTION & DISCUSSION

A. *Theoretical Contribution*

The general theoretical contribution of our building blocks framework is that it connects diffusion research with research on market formation. Firstly, and more specifically, our pattern of development and diffusion (see Figure 1) is an extension of the S-shaped diffusion curve that is typically provided to reflect diffusion processes. We complemented that diffusion curve by adding two new phases that are important for technological innovations, such as autonomous shipping: the innovation phase (between invention of the technological principle and first introduction of an innovation based on that principle) and the adaptation phase (between the first introduction and the start of large-scale production and diffusion). Both phases are empirically shown to require considerable amounts of time (on average about ten years each) [2]. Secondly, we formulated market building blocks and showed how they can be modified to fit a specific industry, in our case the maritime industry. The status of these market building blocks provides an instrument to assess the likeliness of upcoming large-scale diffusion. In short: if all market building blocks are complete and compatible, then large-scale diffusion is possible. That is our third contribution: connecting market building blocks as an instrument to assess the likeliness of large-scale diffusion. In the extant diffusion literature, the focus lies on the form of the curve once it starts. However, the upcoming start of large-scale diffusion is hardly predicted or explored and that is a huge scientific gap because it is widely shown that companies or organizations entering the market just before the start of large-scale diffusion are relatively successful [24].

B. Discussion

It is interesting to see how technological innovations, such as autonomous shipping, do not directly start diffusing on a large-scale but rather are implemented and 'linger' for prolonged periods of time in specific niche market applications. For autonomous shipping this is already visible. Small-scale niche applications of autonomous shipping within territorial waters are for example possible in Norway. Gradually pilots with the technology do evolve in small-scale niche application in which some of the main barriers to large-scale diffusion (for example international regulation) can be circumvented. It is fascinating to observe whether or not and specifically how such niche applications may over time evolve in large-scale diffusion.

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