SUPPLY CHAIN IMPACT OF AUTONOMOUS VESSELS - TOWARDS A RESEARCH AGENDA

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Abstract

Autonomous freight transport is becoming an increasingly relevant topic in transport and logistics. Maritime Autonomous Surface Ships (or MASS) can sail to varying degrees of autonomy, making "smart" shipping possible and sailing with fewer or even full crew members. MASS is intended to enable shipping with lower costs, improved operational performance, greater safety and a smaller footprint. Previous research has mainly focused on technology development, ship design, operational aspects and cost-benefit analyzes of and for autonomous ships. However, the impact and benefits for shippers and other stakeholders in the transport chain – apart from the operator – are rarely elaborated. In this article, we examine MASS from a logistics chain perspective, taking stock of past and current research and projects and proposing an agenda to address key knowledge gaps regarding the impact of MASS on shippers and their supply chains. The benefits of MASS for operators have been well researched, but to what extent does the introduction of MASS lead to significant changes in the proposition of operators towards shippers in terms of freight rates, service offering (routes, lead times, frequency), reliability, and/or footprint? remains underexposed in research. Furthermore, MASS must be integrated into transport systems and logistics chains that must adapt to autonomous ships. The conditions under which these parties want to invest in this integration have not yet been investigated. The research agenda we propose focuses on the most relevant dimensions of this question regarding the conditions for success for MASS, and the subsequent implications for shippers' decision-making and supply chains.

1 Introduction

Autonomous cargo shipping is becoming an increasingly relevant topic in transportation and logistics (Negenborn et al., 2023). Maritime Autonomous Surface Ships (or MASS) can sail autonomously to varying degrees, allowing for "smart" shipping (optimization of ship's behavior through the use of control algorithms) and optionally sailing with reduced crew or even entirely crewless (Hekkenberg et al., 2020; SmartPort, 2018). The technology in the basis consists of a combination of sensors, existing navigation systems (radar, lidar, GPS etc.) and integrated, algorithm-driven control systems on the ship without the need for active human control, at more advanced stages augmented with connectivity features to communicate with other (human-controlled or autonomous) systems nearby.

The first autonomous vessels are already in use, predominantly smaller vessels used for measurements, monitoring or inspections. The next step is to implement autonomy in larger cargo ships, which is challenging due to the more complex operational environment (involving cargo handling and interaction with on-shore equipment and other vessels) in which these operate. Nevertheless, technology development is progressing fast, and various research projects and pilots with industry participation suggest that this technology fills a need. First, there is a growing staff shortage in (maritime and inland) shipping which is not expected to be alleviated any time soon. Second, previous and ongoing research suggests that autonomous shipping presents a feasible business case and allows for footprint reduction of transport.

R&D for autonomous sailing in short sea shipping and inland waterways transport (IWT) often starts from a concrete logistics case in which goods need to be transported between two or more ports. This provides good insight into the requirements that the concepts and technology must meet in order to fit into practice. In the economic analyses, the business case for the ship operator is investigated to determine under which conditions the concepts are economically profitable for ship operators (Kretschmann, 2017).

Despite the use of specific use cases, the impact and benefits for shippers and other stakeholders in the transport chain – apart from the operator – are rarely elaborated upon. The most important added value for shippers that is explicitly mentioned in previous research is that MASS will reduce costs, allow smaller ships to become economically viable and improve the performance of shipping relative to trucking, hence forming an incentive for a modal shift and more sustainable transportation. The question whether logistics and sustainability performance of autonomous shipping concepts is really attractive to shippers compared to existing solutions, and to what extent other stakeholders in the transport chain are willing to invest in autonomous solutions remains underexposed in almost all R&D projects (Kurt & Aymelek, 2022;Nordahl et al, 2023).

In this paper we review past and going research on the development of MASS from the perspective of the logistics chain to identify what benefits MASS can bring to shippers and what role shippers should play to further develop or implement MASS. In addition, we evaluate to what extent there are incentives for parties in the transport chain to invest in logistics solutions with MASS. Due to their final say in modal choice, a closer look at the shipper perspective on autonomous shipping is warranted - importantly, the question whether shippers will be incentivized to adjust their supply chains when MASS becomes a possibility. This adds to existing research by going into the 'why' of MASS, in addition to the technical question of 'how'. In this paper we explore what benefits and opportunities – as well as risks and tradeoffs – autonomous shipping can offer shippers, and what autonomous shipping means for user supply chains.

Section 2 defines MASS and describes the state of the art in the development of MASS. We focus specifically on the technological advances in short sea shipping and inland waterway transport. In section 3, we discuss the benefits for the operators of the vessels. Section 4 we reflect on the technological developments, use cases and benefits from the perspective of shippers and other stakeholders in de transport chain to identify what benefits and impacts they may expect. Finally, section 5 distills from this the most important questions for future research on the application and impact of autonomous shipping and Short Sea Shipping and IWT. Conclusions are drawn in section 6.

2 Maritime Autonomous Surface Ships: State of the Art & Ongoing R&D

2.1 Levels of Autonomy

Before going into further details on the practical use case for autonomous shipping, we briefly discuss the definition of MASS. The technology and applications in autonomous systems – including vehicles – are generally classified along scales ranging from no autonomy (full manual control) to full autonomy (systems that can operate fully autonomously without human control or intervention). Several scales and classifications exist, but for maritime transport the definition used by the Maritime Safety Committee of IMO (International Maritime Organization, the UN agency involved with shipping regulation) is particularly relevant, and will be referred to in this context. IMO recognizes four degrees of autonomy (beyond 'level 0' – ship under full manual control) defined in the table below (definitions quoted integrally from IMO (2018)).

Table 1: Degrees of autonomy defined by IMO

Degree of autonomy	Definition (IMO, 2018)
1	Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control
2	Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions
3	Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
4	Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

2.2 Overview of applications

Technologies and applications for automated and unmanned sailing are being developed for several maritime segments. SMASH, the Dutch Platform for Smart Shipping, has developed roadmaps for the further development of automated and unmanned sailing for unmanned surveillance vessels (USVs), ferry services, inland shipping, short sea and deep sea vessels (see Figure 1).

The development of autonomous, unmanned vessels is most advanced for USV. USVs are small vessels (up to 10 meters) that are used for inspections. The vessels sail a pattern to systematically inspect an area or an object using measurement and observation systems installed on the vessel. A specific type of USV is unmanned underwater vessels (UUV). These are small unmanned submarines with measurement and communication equipment on board. Both USVs and UVVs can be controlled remotely, but with unmanned vessels less personnel is required. The development of USVs is moving quickly because they are often used on the open sea where there are few risks and the ships can hardly cause damage to other ships due to their limited size. The investment costs are also relatively low and the lifespan relatively short compared to other types of ships.

Inland ferries are vessels that are used to transfer vehicles and pedestrians from one bank of inland waterways to the other. The skipper of a ferry service is an important factor in operating the ferry and ensuring safety for passengers and other waterway users. The availability and high costs of personnel are increasingly a concern for municipalities and provinces, with ferry services forming an important link in the regional transport system. Autonomous ferries that are monitored from a control room could guarantee the continuity and financial feasibility of services. The first commercial applications of remotely operated ferries have been ordered and the prototypes of fully autonomous pedestrian ferries are being tested in practice.

Figure 1: Roadmap SMASH (www.smashroadmap.com)

Table 2: Overview of relevant (pilots) projects and scope, and their inclusion of the logistics chain perspective.

Project	**Scope**	**Logistics chain perspective**
AEGIS (Advanced, Efficient and Green Intermodal Systems) (2020-2023)	Efficient shortsea and IW transport with autonomous vessels.	Main focus on vessel design with attention for context of intermodal freight system, and modal shift potential (Krause et al., 2022)
AUTOSHIP (Autonomous Shipping Initiative for European Waters) (2019-2023)	Two demonstrators (Short Sea and IWT)	Focus on vessel. Includes supply chain and logistics model, business case model, and stakeholder mapping; no explicit comparison of autonomous versus conventional
AVATAR (Autonomous vessels, cost-effective transhipment, waste return) (2014-2020)	Autonomous freight vessels on urban waterways	Focus on vessel design, operations, and use cases for different sectors. Including economic feasibility for operator and novel supply chain concepts (Brauner et al., 2021)
MUNIN (Maritime Unmanned Navigation through Intelligence in Networks (2012-2015)	Short sea focus. Develop concept and demonstrate feasibility of autonomous and unmanned vessel.	Focus on autonomous vessel. Incorporates systems integration and ship-shore communication and coordination, as well as economic, safety and legal assessment. Economic evaluation by Kretschmann et al. (2017)
Novimar (2017-2021)	Vessel train concept (platooning with one leader vessel and (semi-)autonomous followers) for IWT and maritime transport; technical focus (technology development and simulation)	Conducted logistics model and cost benefit analysis (Colling et al., 2022)
Seamless (Safe, Efficient, and Autonomous: Multimodal Library of European Shortsea and Inland Solutions) (2023-2027)	"Developing and adapting the technologies required to deliver a fully automated, economically viable, cost-effective, and resilient waterborne freight feeder service for Short Sea Shipping (SSS) and Inland Waterway Transport (IWT)."	Includes work package on 'Redesigning Logistics' (ongoing)

In this article we take a closer look at developments in IWT and short sea shipping. Over the past 10 years technology developers, transportation and logistics companies, knowledge institutions, and governments have worked together in R&D projects to develop the technology and use cases for MASS (see a selection of projects in Table 1). The core of the developments are outlined in the following sections. There are no specific use cases yet in the field of autonomous sailing for deep sea vessels, as the use of autonomous vessels in international waters requires IMO regulation that is currently under development.

2.3 Short Sea Shipping

A large share of past and ongoing research on MASS considered short sea shipping routes on the open sea between European sea ports and in the Norwegian fjords. Short sea shipping does not always mean large ships: Ships developed for the Norwegian fjords are sometimes comparable in capacity to container ships that are used in inland shipping in the Netherlands or on the Rhine.

One of the first major research projects into autonomous shipping in Europe was the Munin project, which included a design for an autonomous, unmanned bulk carrier. With unmanned autonomous sailing, the design of the ship can be adjusted because housing for the crew is no longer required. The ship becomes more energy efficient because the crew facilities no longer use energy and the ship can transport more cargo. The ship only sails autonomously and unmanned at sea. Near the port a crew comes on board to steer the ship in the port. In the project, an initial elaboration has been made of a shore control center from which the ships are monitored. The basic principle is that the ship is able to sail autonomously and the operators in the shore control center only take control of the ship when human intervention is required. The Novimar project also focused on autonomous sailing at sea. As with truck platooning in road transport, research has been conducted into the feasibility of having ships sail in a convoy where the 'follower' ships only have a crew board the ship in order to operate the ship within the port. The project focused on the design of the ship, the operating system and the preconditions for application and the business case.

A major project in practice is the development and construction of the Yara Birkeland, started in 2017. The ship Yara Birkeland was developed to transport fertilizer produced at Yara's factory in Herøya (Porsgrunn) in containers across the Frierfjorden to Brevik (13 km) and later via the coastal waters to Larvik (56 km). The objective for Yara is to realize a modal shift from road to water. The ship with a capacity of 120 TEU is electric and designed to sail autonomously. The ship sails the route several times a week and a journey takes approximately 2 to 5 hours depending on the trajetory. The challenge of developing the technology for autonomous sailing has been taken up by Kongsberg. Masterly, a joint venture of Wilhelmsen and Kongsberg, will manage and operate the vessel from a shore control center in Horten. The ship has been sailing with a crew on board since 2021 and the ship has been connected to the shore control center since 2023. However, the National Maritime Authority has not yet given permission to sail the ship without a crew. In addition, Kongsberg and Masterly are working with ASKO Maritime to operate two ferries on the Oslofjord between Moss and Horten. The ASKO ferries will transport trailers that supply ASKO stores so that they no longer have to drive around the Olsofjord. The ferries have a capacity of 16 trailers. The Autoship project was conducted to further develop the technology for autonomous sailing at sea. The use case in which the technology was tested is the transport of fish feed from factories on the Norwegian coast to fish farms at sea. The Eidsvaag Pioner has been equipped by Kongsberg with technology for autonomous sailing and remote monitoring and control from the shore control center of Masterly. A successful test was carried out in 2023 in which the ship traveled a distance of 160 miles from the port of Averøy to the fish farm and back.

Strengthening the modal shift from road to water is an important driver for the European Commission to stimulate the development of autonomous sailing in short sea shipping. The Aegis (Advanced, Efficient and Green Intermodal Systems) project aims to develop a solution to transport short sea cargo by water to smaller ports on the Norwegian coast with a mainport-feeder concept (mother-daughterships). It is being investigated whether this concept, which is not profitable with conventional ships, is financially feasible with autonomous ships. An additional complexity is that the small ports themselves have no facilities to load and unload containers from and onto ships. To achieve this, the autonomous ships must also have autonomous container handling systems. The ships and container handling technology are being developed in the project. The analyses show that the operation with multiple, smaller autonomous feeder ships can indeed be carried out at lower costs, but no definitive answer is given as to whether the entire operation can compete on cost and service level with the current situation in which containers are transported by road. The MOSES project is also working on concepts that enable modal shift to and from smaller ports. MOSES has worked on technical solutions to be able to moor ships autonomously and to load and unload containers autonomously with a crane installed on the ship that can also be operated from a shore control center.

The development of autonomous sailing is currently at TRL7 (Technology Readiness Level). The technology for autonomous sailing at sea has been applied and tested in a specific practical situation under controlled conditions. At the moment, the Yara Birkeland and the ASKO Ferries in Norway are the only projects in which autonomous sailing of cargo ships is being put into practice. The autonomous container crane has been tested in a demonstration environment. The development and testing of technology that makes sailing an autonomous ship in a busy port such as Rotterdam possible has not yet started.

2.4 Inland Waterways Transport (IWT)

The Novimove project aims to improve the competitive position of inland shipping on the Rhine, relative to road transport, and thus stimulate a modal shift. Various challenges that currently negatively affect the performance of inland shipping are investigated and various technical and logistical solutions are proposed, including automation. Applications for autonomous sailing in inland shipping have also been proposed in the AEGIS, Autoship, Novimar and Seamless projects. In these projects, however, the focus has mainly been on the technical aspects of the issue, namely the design of the ships and the application of sensors and integrated systems. City distribution is a specific use case of autonomous IWT, that is currently explored in – among others – the Avatar project in the Netherlands. The focus here is also mainly on the technology and less on the logistics aspects and implications for the recipient/shipper.

In addition to research and development in research projects, concrete steps are also being taken in practice on the roadmap to autonomous sailing in inland waterway transport. A first step towards autonomous sailing is the track pilot. A track pilot can best be described as an automatic pilot that can keep an inland vessel on course on the waterway, taking into account bends, currents and depth of the waterway. Where an autopilot simply maintains course on open water, a track pilot takes conditions in the waterway into account. A track pilot does not automatically have a view of the ship's surroundings (situational awareness) and therefore cannot take other traffic on the waterway into account and will not avoid other ships. The deployment of track pilots is developing fast. In 2023 approximately, 1000 trackpilots have been installed on inland ships. A next step is the development and market introduction of intention sharing. The suppliers of trackpilots are developing capabilities that ships can exchange their calculated courses automatically. This allows them to identify potential collision courses and alert the captain of the ship.

Another technology towards automated sailing and ready for industry wide deployment is the option to control an inland vessel remotely. Seafar offers remote control service to operate a ship from their control center in Antwerp. This makes it possible to sail with a smaller crew or sometimes entirely crewless. Sailing with a smaller crew is precondition for the business case for remote control. However, there are regulations regarding crew requirements and traffic rules that do not currently allow crewless sailing. In Flanders, Vlaamse Waterwegen NV has given Seafar permission to have the captain perform his duties not on board, but from the shore control center. In the Netherlands, Naval Shipping is the first inland shipping company that is exploring the possibility of sailing with a smaller crew and support from a shore control center in the design of new ships. The 10 River Drones that are now being put into service step by step are equipped to sail with a crew of 3 instead of 5.

3 Benefits for ship operators

The development of MASS is mainly driven by the expected benefits for the ship operator. The benefits of automation to the operator have already been researched quite extensively, so a summary will suffice before discussing how this would impact the proposition to shippers and the implications for supply chains. Fundamentally, automation must make economic sense for operators to provide them with an incentive to invest (Kretschmann et al., 2017). Several studies conclude that the lower operating costs of MASS ultimately compensate for the higher investment costs in advanced technology.

- **Savings on crew costs**. If the crew can be reduced or even completely removed, this could result in savings of up to 20-30% for maritime shipping (Technical University of Denmark, 2017). For inland shipping (with smaller volumes with a fixed crew size, which means that crew costs represent a relatively large part of the OPEX) this may even be higher (Beelen, 2011). The need for a shore control center will generate additional costs, but these costs can be shared among several ships due to economies of scale in operation (Santos & Guedes Soares, 2018). Before the crew can be completely removed from board, there are still a number of challenges to be overcome for which the technology does not (yet) offer a ready-made solution (Kooij et al., 2018). Economically, more onshore workers (in the control center, at terminals and in port services) may be required to perform tasks previously performed by crew on board, which could result in a net increase in costs (Hogg & Ghosh, 2016; Streng & Kuipers, 2020).

- **More efficient sailing** Studies assessing the economic performance of autonomous ships typically assume that autonomous ships sail "smarter" than conventional ships, optimizing speed and route for lower fuel consumption and reliable arrival times. Empirical evidence for efficiency gains from MASS is still scarce because the technology is hardly applied in practice, but intuitively it makes sense because decision support algorithms can make these optimizations better based on a wealth of available information (e.g. GPS, weather, engine performance) than sailors without any decision support. These gains are already within reach with the various smart assistance systems at IMO autonomy level 1. It is also assumed that autonomous ships have more efficient port calls On the one hand because no more time is needed to replenish the ship for supplies needed by the crew and on the other hand due to optimization of the ship's sailing speed thanks to improved communication and coordination on the ETA with terminals and port services (Eijk et al., 2018). MASS can also contribute to the process of port call optimization through improved communication between ship and terminals and port services, which increases the time in port or the reliability of handling and the possibilities for slow steaming (Eijk et al., 2018). Currently, waiting times and travel between terminals in the seaport mean that the time ships spend in front of or in the port is significant (NOVIMOVE, 2021). Although the reliability of autonomous systems themselves is a relatively well-researched topic (Li et al., 2023), how exactly the reliability and predictability of services are affected by automation has not yet been deeply investigated.

- **More efficient ship design.** A general conclusion from the literature on cost-benefit analyzes of MASS (Gu et al., 2021) is that savings on crew costs alone are not attractive enough to offset investments in an autonomous ship, the shore control center and additional costs in ports, but there is greater savings potential through changes in ship design that become possible when ships sail without crew. Research indicates that sailing efficiencies can be achieved when ships are designed for full autonomy, enabling a lighter design with lower fuel consumption, allowing better use of onboard space for cargo transportation, reducing drag and fuel consumption by eliminating crew accommodations and infrastructure and eliminating energy consumption that would be required by the crew (Cross & Meadow, 2017; Gu et al., 2021; Kretschmann et al., 2017; Munim, 2019). On the other hand, autonomous ships are also increasingly technically complex due to detection and control equipment and the need for redundancies (MUNIN project, 2015; Rolls Royce (AAWA: Advanced Autonomous Waterborne Applications), 2016; Technical University of Denmark, 2017) – and therefore more expensive (Kretschmann et al. (2017) assume a 10% cost increase for new construction). It can be expected that this technology – which is now being implemented on a limited scale – will become more accessible to a wider range of operators over time. To enable crew reduction, a switch to alternative propulsion systems (hydrogen, methanol, ammonia or battery-electric) is necessary to make the propulsion low-maintenance and easier to maneuver (Akbar et al., 2021; Geertsma et al., 2017; Kooij & Hekkenberg, 2022). The additional investments and operating costs of alternative propulsion systems are currently much higher than the benefits of autonomous sailing.

- **New business models and services**. If MASS can sail completely without crew, they can also be downsized while still being economically viable (Theotokatos, 2023), opening up possibilities for concepts such as mother-daughter-vessels (Akbar et al., 2021), ship platooning (Alias & Felde, 2022; Colling et al., 2022) or smaller services on routes where shipping was previously not possible or economically feasible. These models are not necessarily based solely on fully automated ships; for example, Akbar et al. (2021) consider the case where a manned 'mother ship' (complying with international manning regulations) sails to hub ports where smaller autonomous ships (permitted by local regulations) transport the cargo to smaller ports close to the final destination lie (Krause et al., 2022). The NOVIMAR project (e.g. Colling et al., 2022) – has focused on the Vessel Train concept in which a manned 'leader' ship leads a group of autonomous 'follower' ships. This reduces crew costs and allows smaller ships to access waterways (for example in urban centers) that are too small for conventional ships. However, ship trains require large freight volumes to be economically viable. In general, new operating models take advantage of the fact that autonomous ships are more likely to be economically feasible with a small cargo volume, allowing for higher frequency services with more and smaller ships. This makes it possible to set up new services on smaller waterways where inland navigation was previously not feasible (Brauner et al., 2021; Krause et al., 2022; Msakni et al., 2020; Potgraven & De Lange, 2022; Rodseth et al., 2020).

The findings discussed above mainly arise from (theoretical) research into short sea shipping and inland shipping. In general, inland vessels are smaller than deep-sea or short-sea vessels and have a smaller crew (but often crew costs represent a larger part of the OPEX (Beelen, 2011; Kretschmann et al., 2017; Technical University of Denmark, 2017)), sail shorter routes, smaller call sizes and spend relatively more time at anchor or in the harbor (Eijk et al., 2018; NOVIMOVE, 2021). With a limited crew and limited working hours, as is common in inland shipping, autonomous sailing can enable longer operating hours or even continuous use of inland vessels (Eijk et al., 2018). Regarding cost-effectiveness, Panteia (2021) concluded that partial automation under the right conditions (legislation and public investment in infrastructure enabling autonomous ships) offers an attractive business case for larger operators. The policy context is also important: inland shipping and short see shipping are specifically encouraged as part of the solution to transport emissions and traffic congestion, with the European Smart Mobility Strategy (2020) aiming for a modal shift in freight transport from road to inland shipping.

4 Analysis from a logistics perspective – A shipper-oriented research agenda

4.1 A shippers perspective

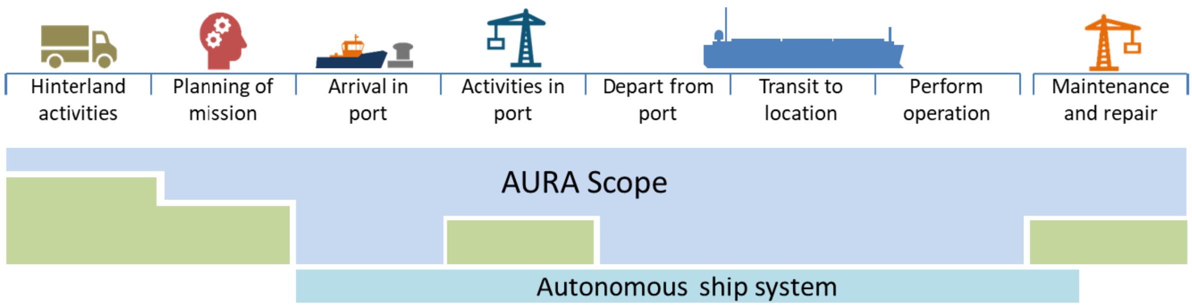

Figure 2: AUTOSHIP Reference architecture (AURA) operations model D2.5

While the development of MASS appears to offer advantages for ship operators, the question is what effects and benefits this has for the logistics chain and in particular for shippers. The development of MASS becomes interesting for shippers if it offers opportunities to significantly improve the performance of the supply chain in terms of responsiveness, robustness, reliability, lead time, sustainability or costs of the shipper's supply chain and not just the performance of the transport chain. In that case, it is also important for shippers that MASS is further developed and introduced. The question is how MASS can

change the proposition of short sea and inland shipping operators in terms of freight rates, service offering (routes, lead times, frequency), reliability and/or footprint.
We distinguish four types of impacts to analyze the benefits of MASS for shippers.

- **Type 0: No noticeable impact on proposition for shippers**. The effects of the introduction of MASS are limited to ship operators and stakeholders in the transport chain involved in the handling of MASS in ports and at sea. The strength of MASS lies in solving bottlenecks within the transport chain and offering continuity in the current services of the transport chain during structural changes. For example: the increasing shortage of labor. Or meeting the extra demand for shipping capacity (and therefore crew) at low tide on the rivers. Any cost benefits from MASS are too small to pass on in a price reduction that would cause shippers to adjust supply chain design and operations.

- **Type 1: Better freight rates and service levels for shippers already using short sea shipping and inland shipping**. How will MASS change the current proposition of inland shipping towards their shipper customers in terms of costs, services, reliability and footprint, and if so, under what conditions? For shortsea, this has been explored to a limited extent (see Gu et al. (2021), Ziajka-Poznanska & Montewka (2021), and Dantas and Theotokatos (2023) for recent reviews), generally focusing on the proposal of MASS technology for operators. To better understand the introduction and future trajectory of MASS, it is necessary to evaluate whether MASS enables operators to develop a more attractive proposition for shippers:
  - What levels of net savings are substantial enough to reduce shipper rates?
  - Does MASS make it attractive enough for operators to deploy smaller vessels and increase service frequency, and does that frequency increase lead to lower inventory levels in the chain?
  - Can MASS itself guarantee a more reliable (predictable) service and can shippers therefore reduce their safety stocks in the chain?

  A theoretical example for the impact of MASS on the supply chain in the dry bulk chain is presented by Küchle et al. (2023). It indicates that smaller autonomous ships can reduce pipeline inventories by customers. On the other hand, Samskip intends not to adjust the timetable of container services with the Seashuttle in the future.

- **Type 2: Modal shift with existing services** Will the improvement of services by MASS in the current short sea shipping and inland shipping services stimulate the modal shift from road transport to shipping? Does MASS provide such an improvement in services that short sea and inland shipping are now beneficial? This is highly dependent on the extent of the rate reduction and service improvement. When considering the modal shift, not only developments in shipping are relevant, but also developments in competing modalities, especially road transport. In road transport, autonomous driving technology is also emerging, including truck platooning, as well as a transition to emission-free freight transport (with electric or hydrogen-powered trucks, for example). This means that in the long term the modalities will no longer be able to distinguish themselves in terms of sustainability. Because the expected impact of MASS on the services and prices of short sea and inland shipping of existing operators is still barely understood, the impact on the modal shift cannot yet be determined. There is also little research on price and service elasticities for modal shift to determine how large rate and service improvements need to be to have an impact for shippers.

- **Type 3: Modal shift with new concepts and services**. Will autonomous shipping provide opportunities for new short sea and inland shipping services and facilitating modal shift? Research focusing on MASS operations provides numerous suggestions for new control models that become possible when (inland waterway) vessels operate autonomously. These include vessel trains, mother-daughter ship systems, sailing on smaller waterways and calling at previously inaccessible ports (with smaller ships), and the use of autonomous ships in last-mile distribution via urban waterways. For all these proposed models, it is worth exploring when and under what conditions the proposition will work in a way that is attractive to shippers and economically and operationally feasible for the operator. Shippers who could potentially be served by new autonomous water services currently use other modes of transport – mainly road transport – and would need to be convinced of the MASS proposal before they are incentivized to make this modal shift.

The answers to the questions discussed above will vary considerably per segment. The literature on MASS in shortsea shipping takes this into account for different segments, for example bulk, container and RoRo shipping. These segments must also be considered separately in inland shipping. When assessing the use case and potential impact of MASS, the supply chain structure for these segments should be taken into account (e.g. the container chain differs significantly from wet or dry bulk), the predominant business model (scheduled service, time/travel charter etc. .)), the importance of speed, reliability, flexibility and price for the competitiveness of water transport (in case of competition with road transport), port and terminal processes and coordination between ships and shore, as well as safety and legislative issues. This helps to assess where the use case for MASS is strongest and where it will have the most impact.

4.2 A transport chain perspective

In addition to the impact on shippers, other stakeholders in the transport chain will also have to make adjustments to their processes to be able to handle MASS. These include terminals, boatswain, pilots, tugboats, port authorities, other shipping traffic and security services. Despite the fact that the need for these parties to adapt is mentioned by various stakeholders, little research has been done into the necessary adjustments and the business cases of these stakeholders. This leads to the following two research questions:

a. **How will MASS affect (inland) port call planning, and how will this take effect down the chain?** Previous research on MASS generally envisages improvements in reliability and predictability of port calls, and shorter turnaround times. This may work out differently for different terminals, of which the scale and operating model can differ considerably. First, we are interested to know if and when this is really the case, and how the planning of terminal activities and port services can also impact on port call efficiency and turnaround time. Second, the question is what impact the potential efficiency gains in port will have down the chain in terms of cost and lead time reduction and reliability improvement – will shippers benefit enough to prefer autonomous shipping and/or adjust their supply chain design? If other factors impacting on port call and transshipment efficiency are not addressed as well (e.g. waiting times, congestion), efficiency gains from MASS along the supply chain may be limited. Hence this issue factors into the considerations regarding the questions above.

b. **How should terminals, infrastructure managers, and port service providers operationally adapt to autonomous ships?** The considerations directly above illustrate that realizing the potential benefits from MASS along the supply chain also depends on adaptation by other stakeholders, notably terminals, port service providers, and infrastructure managers. In the previous section we referred to earlier research briefly discussing terminal (re-)design for autonomous shipping, generally mentioning large investments in infrastructure and automation. For terminals going this route, it is relevant to carefully evaluate what investments are necessary and how terminals and terminal processes can be best (re)designed with MASS in mind. On the other hand, far-reaching investments in infrastructure and equipment onshore may not always be necessary if more onshore personnel is employed to perform tasks previously performed by onboard staff (Streng & Kuipers, 2020) – ultimately adoption will depend on the business case. The same applies to other port services (tugs, pilots, bunkering) and relevant infrastructure (e.g. locks), all of which require an evaluation of how current processes will be impacted by autonomous shipping, and how (a mix of) automation and process (re-)design can help accommodate autonomous vessels. The key question across the board here is how tasks and responsibilities can be best divided between MASS vessels (with reduced or remote crew or fully autonomous) and entities with which they interact. This requires an evaluation of current (technical and organizational) options, the associated investments and risks, and what this means for the long-term trajectory of adoption of MASS and adjustment of other actors in the waterborne transport system.

5 Conclusions

This article examines how autonomous shipping (or MASS) in coastal and inland shipping can impact supply chains and more specifically shippers and other players in the transport chain. We started by noting that existing research on MASS focuses mainly on the technology of the ship and the business case of the ship operators and that there is little attention to the supply chain outside the operator. Research on MASS highlights the potential of autonomous shipping to increase the competitiveness and attractiveness of water transport. Therefore, a closer look at the potential of MASS is warranted, as well as a thorough evaluation of MASS from the shipper's perspective, as she is the one who has the final say on the choice of transport mode.

The crucial question is whether MASS will enable operators to offer new, better and/or cheaper services to shippers, which are attractive enough for shippers to prefer water alternatives to road transport? We distinguish four types of impact with which the impact of MASS for the shipper can be mapped: (0) the introduction of MASS has hardly any influence on the shipper. MASS guarantees the continuity of waterborne transport with the increasing scarcity of personnel and any cost benefits for ship operators are used for investments in facilities or the energy transition, (1) change in the price/quality of services for shippers who already use inland shipping allowing shippers to improve their supply chain performance. (2) change in price/quality of existing inland shipping services, making a modal shift possible. (3) introduction of new concepts and services on routes or for cargo flows for which no waterborne transport service was yet offered and modal shift becomes possible.

Much research is aimed at developing concepts that contribute to impact type 3. But we have not been able to find analyzes that demonstrate under what conditions MASS has a competitive proposition compared to road transport. How the deployment of MASS is reflected in the service offering (services, rates and performance) to shippers and how this affects the logistics decisions of shippers is mediated by contextual factors in the shipper's supply chain and also actions of other relevant actors in the transport chain when it comes to the handling of autonomous ships in ports. Most of these contingencies – which determine the success of MASS in practice – have not yet been investigated.

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