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**Extended Study Outline**

# Study on the Economic Implications of Maritime Autonomous Surface Ships (MASS)

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# Content

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*www.cml.fraunhofer.de/en/press/studies/study_on_cost_and_quality_of_service_implications_of_MASS.html*

# Executive Summary

While there have been detailed investigations on the effects of Maritime Autonomous Surface Ships (MASS) on the regulatory model as well as on its technical details, analyses on the economic effects are comparatively scarce.

For MASS concepts to reach their economic and sustainability potential, a change in maritime logistics operations is a prerequisite. Therefore, these concepts should be viewed from a holistic perspective.

This study provides a step towards such analyses by investigating the effects of MASS on ship operating costs and the overall implications regarding supply chain efficiency.

It is explained how the operating costs of a MASS would differ from traditional vessels using an example of handy-size bulk carriers operating in the Baltic Sea.

Additionally, possible implications for the shippers in the context of MASS are assessed. E.g., the quantification of effects of more reliable and transparent lead times on inventory holding costs, analysis of expected improvements in customer service and exploration of different supply chain configurations.

This study is based on data of average operating costs in 2020 of a handy size bulk carrier. The data is supplemented by an extensive literature review on MASS itself, ship operating costs, ship insurance costs, port/terminal access regulations & limitations, supply chain metrics and inventory cost models. Further, interviews with leading experts on MASS technology as well as with experts in ship-operation, -building, -insurance and supply chain management are carried out.

Using both quantitative and qualitative analysis based on bulk shipping in the Baltic Sea allows a holistic view on costs and impacts on the whole supply chain.

The results of this study demonstrate a potential of MASS regarding cost savings on the carriers' side. MASS facilitate the realization of significant economies of scale, which increase the more ships are being controlled from a single RCC and the bigger the crew of the substituted conventional vessels.

The analysis of service quality indicators in commercial shipping and their respective influence on dependent supply chains demonstrates a potential, not only for supply chain resilience, but also for value creation on the shippers' side due to savings in inventory costs.

Besides the specific analysis of the chosen case, the study offers impulses for the exploration and identification of economically viable MASS operations in different shipping sectors. Here, short sea shipping is found to be an ideal area of application for the early adoption of MASS technology.

For more detailed information and results please refer to the full version of this study.

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# List of Abbreviations

| | |
|---|---|
| **AI** | Artificial intelligence |
| **AIS** | Automatic identification system |
| **AKOON** | Automated and Coordinated Navigation of Inland Ferries (German acronym) |
| **AR** | Augmented reality |
| **CAPTN** | Clean autonomous public transport network |
| **CML** | Center for Maritime Logistics |
| **COLREG** | International regulations for preventing collisions at sea |
| **e.g.** | Exempli gratia |
| **Et al.** | And others |
| **ETA** | Expected time of arrival |
| **FernBIN** | Remotely controlled, coordinated navigation on inland waterways (German acronym) |
| **FOCUS** | Fleet optimal control unified system |
| **i.e.** | Id est |
| **IMO** | International maritime organization |
| **ISO** | International standardization organisation |
| **KASS** | Korea autonomous surface ship project |
| **KPI** | Key performance indicator |
| **Ltd.** | Limited |
| **MASS** | Martime autonomous surface ships |
| **Nav** | Navigational |
| **NPV** | Net present value |
| **p.a.** | Per annum |
| **RCC** | Remote-control centre |
| **S&P** | Standard & Poor |
| **Trad.** | Traditional |
| **USD** | United States Dollar |

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# 1 Introduction

**A lone captain enters the bridge and starts the working day by screening the status of the vessel. She is currently underway in Skagerrak and about to enter a traffic separation scheme westbound. The automated lookout system reports an overtaking vessel portside, which is passing slightly too close for comfort and is flagged for further observation.**
**The captain acknowledges these reports and moves on to review current and forecasted weather data, as the navigation system adjusted the course slightly to the north to avoid the backside of an approaching low-pressure system.**
**A yellow light is flaring up: The maintenance system has detected a deviation from optimal performance of the bow thruster and recommends the scheduling of a maintenance technician in the next port of call as the data suggests a defect in the near future.**
**After completing these daily checks, the captain puts the vessel back in autonomous mode and heads out for a coffee break. There, on the balcony of the remote-control centre, they meet with a fellow captain, who is eager to discuss their vessels encounter with fishermen in the Biscayan just this morning.**
**A notification sound emerges from a phone, and the captain quickly moves on to a monitoring task in the eastern Baltic, where a vessel has called for human supervision as it is about to enter the port of Gotland.**

Visions, such as above have been prevalent in research and science for a long time and have been at the center of a variety of technology developments and demonstration cases for more than a decade. The results range from descision support over remote-controlled vessels and onboard automation up to integrated and innovative unmanned vessel designs. Smart, autonomous and unmanned vessel operations are standard terms on maritime outlook reports.

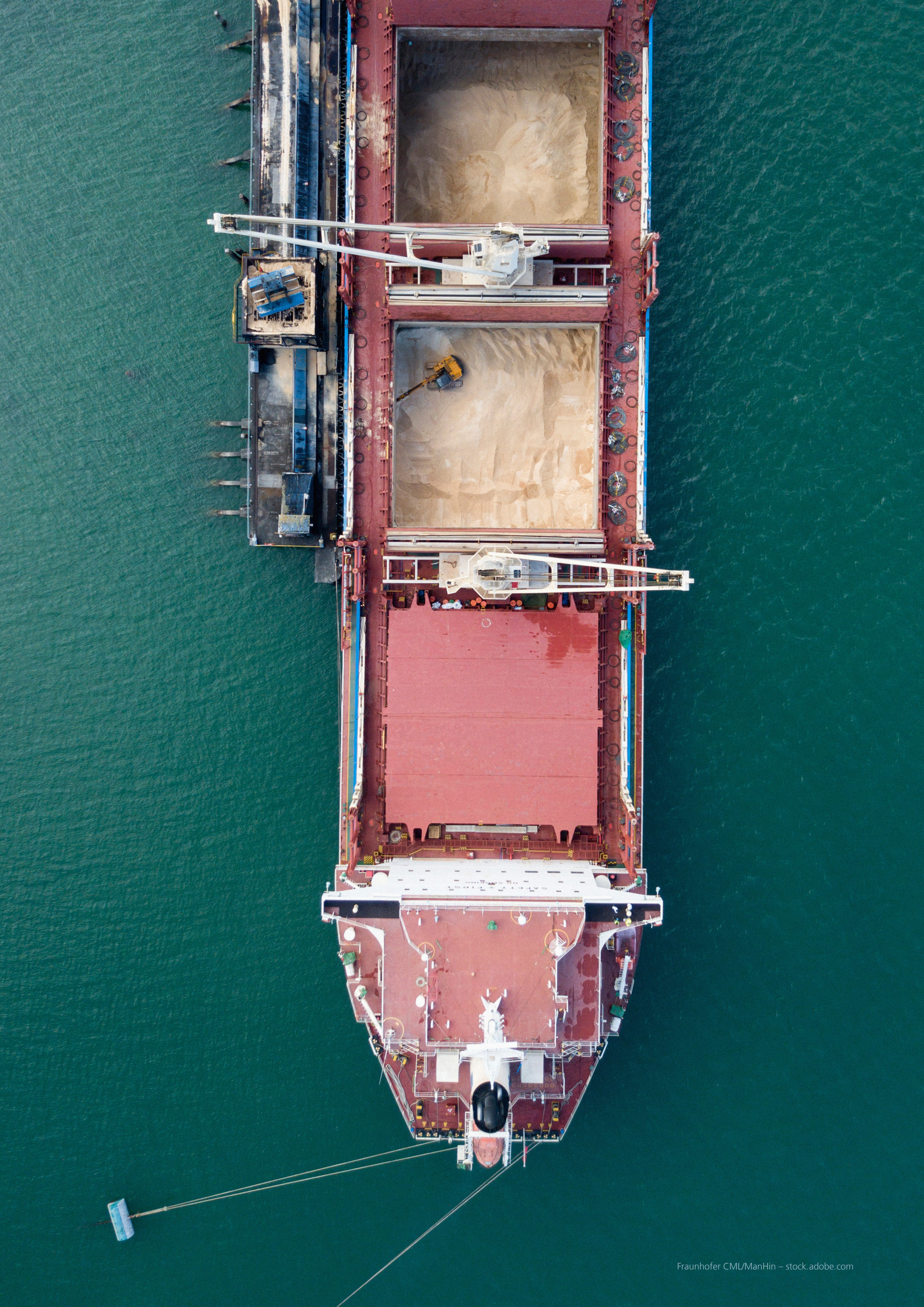
While the applicability of those concepts has been demonstrated to the public as well as technology-savvy people on a variety of occasions and technology readiness seems to be accepted by most relevant experts at this point, many discussions about MASS (Maritime Autonomous Surface Ships) are still primarily related to technological and regulatory questions.
Nevertheless, it needs to be acknowledged that despite all innovative approaches, autonomous maritime technologies must serve maritime business models to have a positive impact on supply chain services. While many loose references to operational costs savings or even logistics effects of MASS are highlighted by technology providers, an estimation of the specific effects does not fit the scope of most investigations.
After an overview of the current state of MASS research and development, this white paper focuses on these two questions:

**Which effects can MASS have**

- **on ship operating costs?**

- **on supply chain efficiency?**

While the specific effects are naturally trade and vessel dependent, this study is assuming a theoretical transport case in the Baltic to provide first insights based on empiric AIS data, expert interviews, and ten years of in-house experience.
The approach itself is of course transferable to other trade cases and vessels sizes.



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# 2 MASS – An Overview

## 2.1 MASS Elements and Technologies

IMO has defined Maritime Autonomous Surface Ships as ships which can, to a varying degree, operate independently of human interaction. In total, four different degrees are described, even though it must be noted, that one MASS can operate in different degrees during a single voyage (IMO 2021).

The degrees are:

**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 sometimes 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.

Realizing those different degrees on a MASS requires a number of technologies and systems that need to be applied in comparison to traditional manned vessels. Within the Within the International Standardization Organization (ISO) autonomous ship system terminology has been defined.
Typical elements of an autonomous ship system are (ISO/TS 23860:2022):

- **An autonomous onboard controller**, which executes control under certain conditions without human assistance

- **A remote-control centre (RCC)**, which is a site remote from the ship from where control can be executed

- **Connectivity**, all network facilities maintaining communication between the ship and all autonomous ship systems

- **Local sensor systems**, which are outside the vessels and provide additional data from the operating area

Regarding the onboard systems, typically a further differentiating is being made regarding a sensor-based situational awareness system taking care of the lookout duties, an autonomous navigation system taking care of nautical decision-making onboard as well as (extended) engine automation system ensuring the capabilities of the technical system (Burmeister et al. 2014).

Ashore, operational modes can be further clustered depending on the capabilities of the operator to interact with the MASS, which can range from direct, via tactical or strategical control down to pure system monitoring.

## 2.2 MASS Technology Readiness

MASS is no longer a mere future vision, although a commercial use of a fully autonomous vessel has not been realised yet. The following chapter provides an overview of recent research and demonstrators in the area of MASS.

The introduced projects are divided in relevant research projects with demonstrators and industry participation as well as planned or in trial phase industrial applications.

The timeline in Figure 1 provides an overview on current developments in ongoing or ended public and industry funded projects.

Detailed descriptions of the projects, trials and achievements can be found in the full-length study.

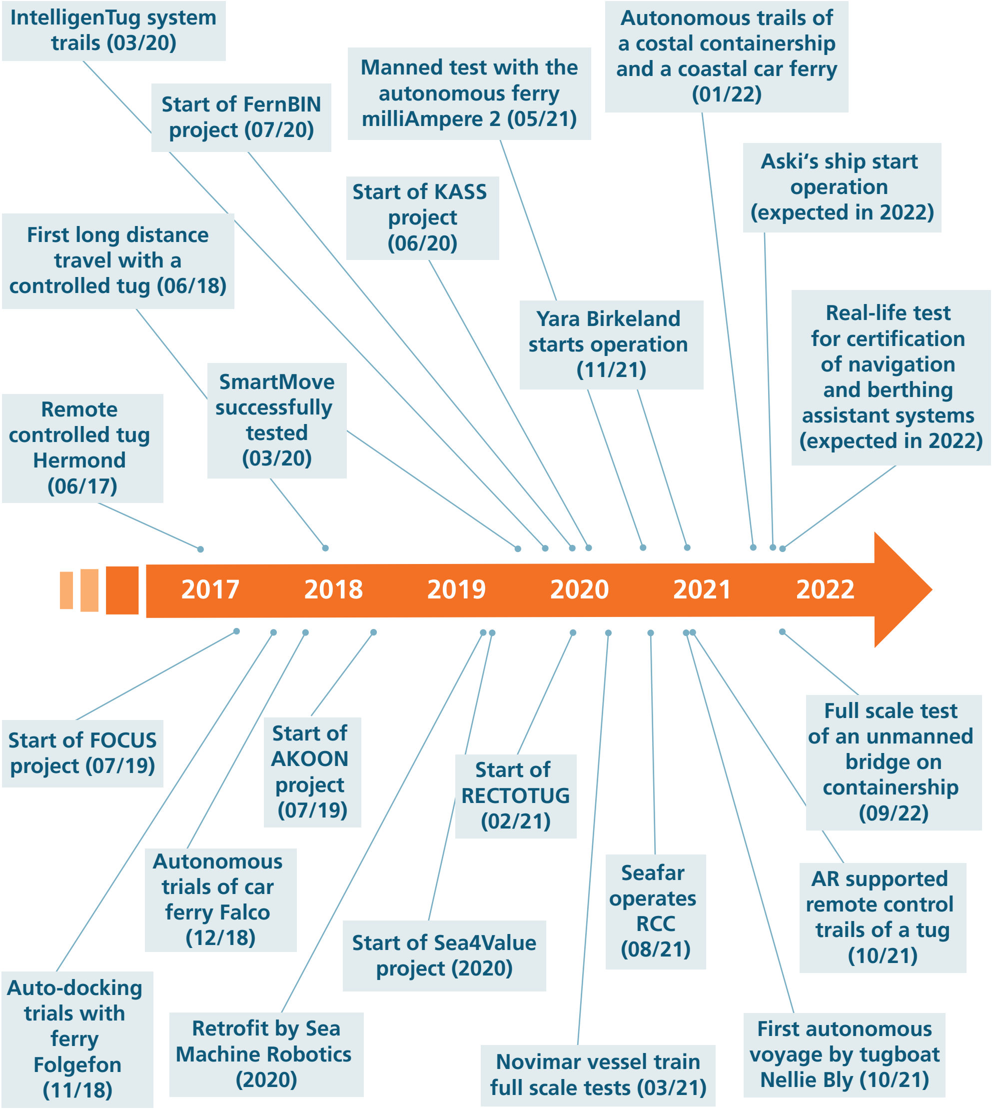


*Figure 1: Timeline and state of the art of MASS*

# 3 Economic assessment

## 3.1 Methodology

In order to assess the future economic viability of MASS, this study uses a methodology based on comparing the economics of a conventional vessel to a MASS.
The underlying assumption is, that since freight rates are set by exogenous determinants such as supply and demand of carrying capacity and commodity prices, both – the manned vessel and the MASS – have the same potential to generate earnings.
Therefore, a focus on analysing the cost structure of manned and unmanned maritime transport allows to assess differences in prospective profitability for a carrier.

To conduct this cost-centred analysis the study uses data compiled in Drewries' Ship Operating Cost Report 2020 as a baseline of comparison.
The cost reference model for a conventional bulker is based on the aforementioned data on operating costs, supplemented with an AIS-derived exemplary operational profile of an actual handy-size bulk-carrier.
Since fuel prices have a strong fluctuation, the calculated fuel consumption will be provided in tons rather than USD, to facilitate the comparison under deviating fuel prices. The capital costs are based on the recent global average price of newbuilt handy-size bulk carriers and are included in the form of a net present value. Detailed values, calculations and descriptions of assumptions are found in the full-length study.

After having established the reference cost model, expert interviews provide further insights to the prospective effect of MASS-technology on cost structures as well as service quality indicators. Consulted experts include professionals in MASS-research, shipping, marine insurance, and shipbuilding.

These inputs, described in detail in the full-length study,  allow to give quantifiable insights on the cost structure of a potential MASS and will further allow to investigate potential for greater service quality in a qualitative exploration.

Since freight rates are largely independent of transport cost (Oliveira 2014), effects on shippers cannot be quantified in terms on transport cost.
Rather, to investigate any potential effects of substituting conventional vessels by MASS on a supply chain, first a reference model of a supply chain and its inventory management will be introduced and the relationship between several service quality KPI's and the average annual inventory holding costs in this supply chain will be demonstrated.

It will then be discussed in two scenarios whether the expected effects of MASS on service quality indicators such as lead time, punctuality and transparency of information would have effects on the annual inventory holding cost of a company in a maritime supply chain and what scale is required to profit from any cost savings due to MASS.
The first scenario will explore the substitution of a single conventional vessel with a MASS of equal proportions.
The second scenario will focus on the effects of substituting the single conventional vessel with a fleet of MASS.

## 3.2 Reference cost model of a conventional bulker

In this section a reference cost model of a conventional bulker is presented, a list of the cost categories can be found in the full-length study.

### 3.2.1 The Reference Vessel

The ship in question is a handy-size bulk carrier, arranged based on IMO and AIS data analysis from actual bulk carriers operating in the Baltic Sea (Fleetmon 2017; MarineTraffic 2021).

The assumed particulars of the reference vessel can be observed in Table 1.

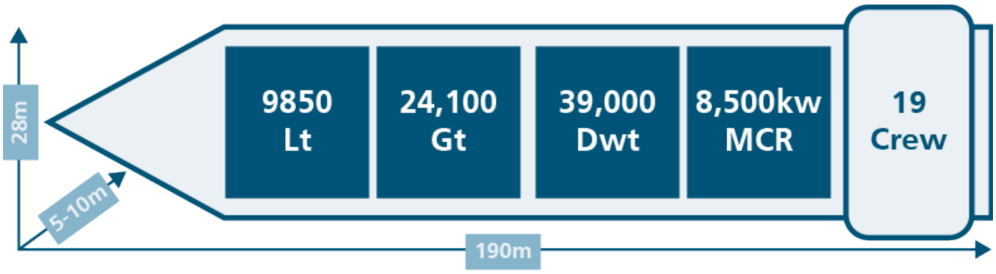


*Figure 2: Vessel particulars of the reference vessel*

**The assumed operating profile of the vessel is derived from 30 days of AIS data from the Baltic Sea and composed as follows:**

| Nav Status | % of AIS Messages | % of Time | Days per Year |
|---|---|---|---|
| **Underway** | 39.8 | 65.9 | 240 |
| **At anchor** | 1.7 | 1.4 | 5 |
| **Moored** | 58.5 | 32.7 | 120 |

*Table 1: Operational profile of the reference vessel, based on ORAWA/ALPPILA Operating Profiles (Fleetmon 2017)*

The observed vessels spent about two thirds of their time at sea and the remaining 125 days either waiting or at quay, while traveling at a mean recorded speed of 12kn.

The shipowner and the carrier are not necessarily the same person or institution in modern shipping. It is common practice that the owner of a vessel, charters the ship out to a different party, typically either in the form of a bareboat charter, a voyage charter or a time charter.

This study will however assume, that the party owning the vessel is also operating it. This means there is no division of cost, risk, or profit. The costs incurred due to owning and operating a vessel can be divided into three categories: Operating Cost, Voyage Cost and Capital Cost.

### 3.2.2 Cost p.a. and NPV of the reference Vessel

While the operating costs are bound to fluctuate with the age of the vessel, given that the average operating costs p.a. are based on a 10-year-old vessel, it will be assumed that they will hold as an average over the complete lifetime of the vessel.

As for periodic costs like the special survey, it will be assumed that the shipowner will build up financial reserves every year, essentially transforming these costs into their yearly averages.

*Figure 3: Distribution of operating cost p.a. of reference vessel*

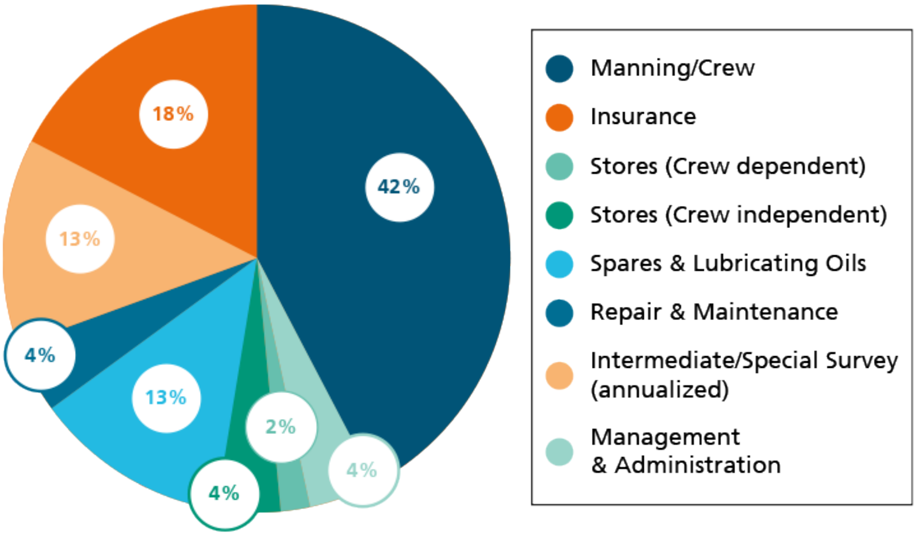


*Table 2: Reference vessel overview of cost p.a.*

| **Operating cost p.a.** | |
|---|---|
| **Total Operating Cost** | 1,880,000 USD |
| **Voyage cost p.a.** | |
| **Fuel Consumption p.a.** | 6,338 tons |
| **Port Call Cost** | 1.00 factor |
| **Capital cost** | |
| **Newbuild Price** | 23,000,000 USD |
| **Salvage Value** | 3,936,000 USD |

To raise the money needed for the initial investment, ship owners typically rely on some form of financing. This includes bank loans such as mortgage loans secured against the ship, corporate loans secured against the corporation, shipyard credit, mezzanine financing, private equity/debt or even the issuing of bonds. (Girvin 2019)

The resulting cost of capital, i.e. the interest of the loan, adds to the initial cost of capital and is usually paid off over many years. However, since the cost of capital depends highly on the financial shape of the shipping company, its credit rating, the size of the loan, projected freight rates, expected profit margins and many other factors, for the sake of this study it will be assumed that the shipowner pays the vessel in full on delivery.

This means that for the eventual comparison of cost structures between the reference vessel and the MASS, the initial investment, and all known cash flows need to be discounted by the cost of equity.

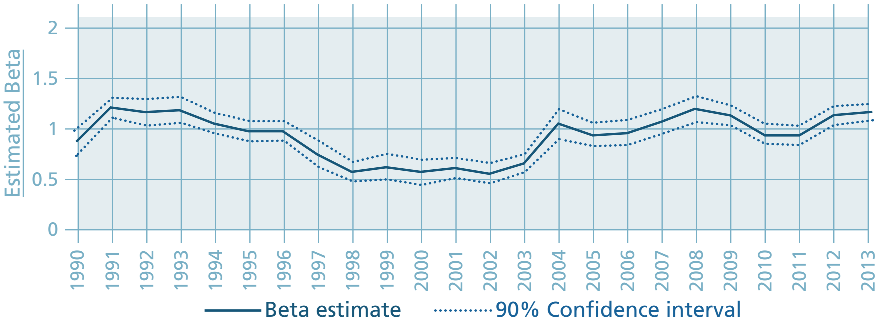


*Figure 4:*
*Historical beta factor of Shipping Companies (Drobetz et al. 2015)*

In order to calculate the cost of equity, the market risk premium is to be multiplied with the industry specific beta factor.

The market risk premium is set at 6-8 %, where this study will use the median of 7% (IDW 2019).
The beta factor provides insight into how much a given industry correlates with the overall stock market, represented by index funds such as the S&P 500. It is used as a catch-all indicator of the return an investment is expected to provide in comparison to the general economic growth.

For some industries this factor is more or less stable, while in maritime shipping significant fluctuations can be seen between companies and over time. (Drobetz et al. 2015)

The cost of equity mainly serves the purpose of a discount rate representing opportunity cost.
As it is additionally assumed that both compared vessels are bought and operated subject to the same determinants, the beta factor will be set to 1, assuming a perfect correlation with global market movements.

The same principle is applied to inflation. As all cash flows in this study are expected to be subject to the same inflation rate, inflation can be factored out. This means all costs become real costs, which are defined in terms of constant dollars.

Based on these values, an estimate of the time value of the total cost over the lifetime of the reference vessel can be calculated in the form of a net present value, omitting voyage costs. Resulting in a net present value, or rather a net present cost, of -40,400,000 USD.

## 3.3 MASS effect on cost model

The following section will detail present the expected costs of a MASS with otherwise the same specifications as the reference vessel.
Detailed expected costs including the comparison to the base case are described in the full-length version of this study.

It has to be noted that the proposed cost effects are assumptions based on various expert interviews, desk research as well as the personal experience of the researchers who are involved in numerous research projects in the field of applied MASS-related research and development.

Therefore, the values should be treated as well-informed estimations rather than hard empiric evidence.

### 3.3.1 Projected cost p.a. and NPV of a Handy-size MASS

*Table 3: MASS – Projected operating and capital cost summary*

| Cost Category | | Cost in USD | Comparison trad. Vessel in % |
|---|---|---|---|
| **Manning/Crew** | | 0 | - 100% |
| **Insurance** | | 72,000 | + 11% |
| **Stores** | | 75,000 | - 47% |
| **Spares and Lubricants** | | 240,000 | 0% |
| **Repair, Maintenance & Intermediate survey** | | 370,000 | + 11% |
| **RCC** | **Large Scale** | 152,000 | + 100% |
| | **Small Scale** | 549,000 | + 100% |
| **Management & Administration** | | 320,000 | 0% |
| **Total** | **Large Scale RCC** | 1,229,000 | - 35% |
| | **Small Scale RCC** | 1,626,000 | - 14% |
| **Capital Cost** | | **22,540,000** | **- 2%** |

*Table 4: MASS - Projected voyage cost summary*

| | | | |
|---|---|---|---|
| **Fuel Consumption p.a.** | 6,021 | tons | -5% |
| **Port Call Cost** | 1.04 | factor | + 4% |

Concerning the NPV, it is assumed that all financial parameters apply the same way as they would in a manned vessel (See 3.2.6).

However, since the scale of the operation will drastically influence yearly operating costs due to differently scaled remote-control centers, net present values will be calculated for both – a small scale RCC in direct remote control mode and a large RCC in remote monitoring mode with several vessels per operator.

However, this also helps to depict the expected development of MASS cost structures over time:

It can be expected that during the ramp up phase of MASS, rather few ships are in operation and will also need quite meticulous supervision, leading to proportionally higher RCC costs per vessel.

In the midterm, larger scale operations, consolidated in single (maybe even independent) remote-control centres are becoming more likely and will help, together with a higher technological maturity and the according policy changes, to further unlock the cost potentials of autonomous fleets.

When compared to the reference vessel, the calculated net present values show a net gain of about 3,100,000 USD when a small

| | | |
|---|---|---|
| **Net Present Cost Large Scale RCC** | -33,240,000 | + 18% |
| **Net Present Cost Small Scale RCC** | -37,300,000 | + 9% |

*Table 5:*
*MASS – Net present cost*

scale RCC is used, as well as by 7,160,000 USD for use of a large scale RCC.
Under the assumption of a micro RCC operating only one MASS with qualified cap-tains at 24/7 as well as one administrative assistant and otherwise no further personnel the net present cost amounts to 39,8 Mio USD showing an increase of 500,000 USD compared to the reference vessel.

So, while the cost advantages are much more pronounced with larger scale operations, in this case, even operating a micro RCC for a single vessel would come with a slight cost advantage.

### 3.3.2 Impact of more reliable lead times (Excerpt from Supply Chain considerations)

Since the implementation of MASS technology is assumed to correlate with increased reliability, service quality insupply chains could be significantly impacted.

The impact of reduced lead time uncertainty has a significant influence on demand during lead time and therefore on safety stocks. Reducing the standard deviation of lead time by half, reduces safety stocks by more than 51% which manifests itself in a 17,5% decrease in annual holding costs.

The effects of an increase in the standard deviation of lead time are equally as pronounced. Here, double the standard deviation in lead time will lead to additional annual holding costs of almost 900,000 USD or 23,3% for the reference supply chain.

This underlines the importance of punctuality in modern supply chains and illustrates why it is one of the most important service quality indicators.

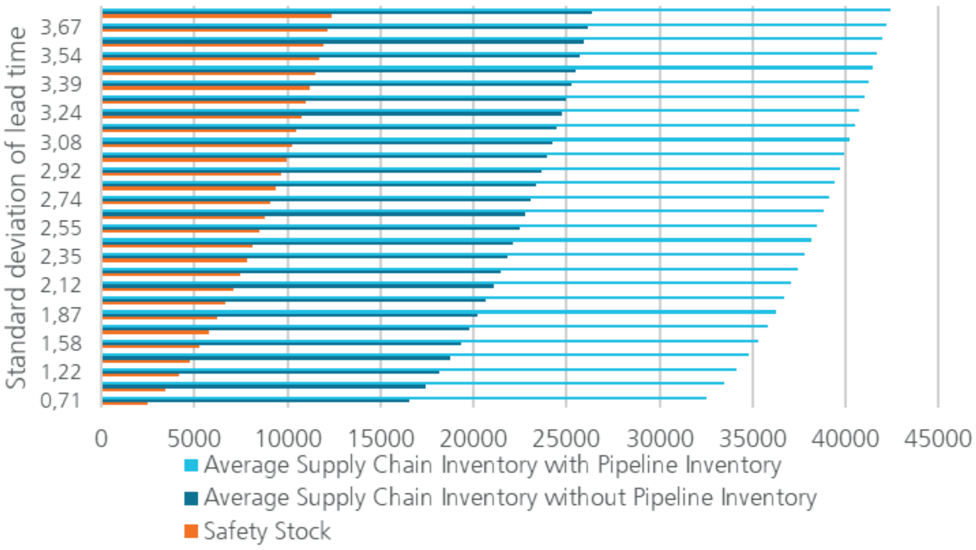
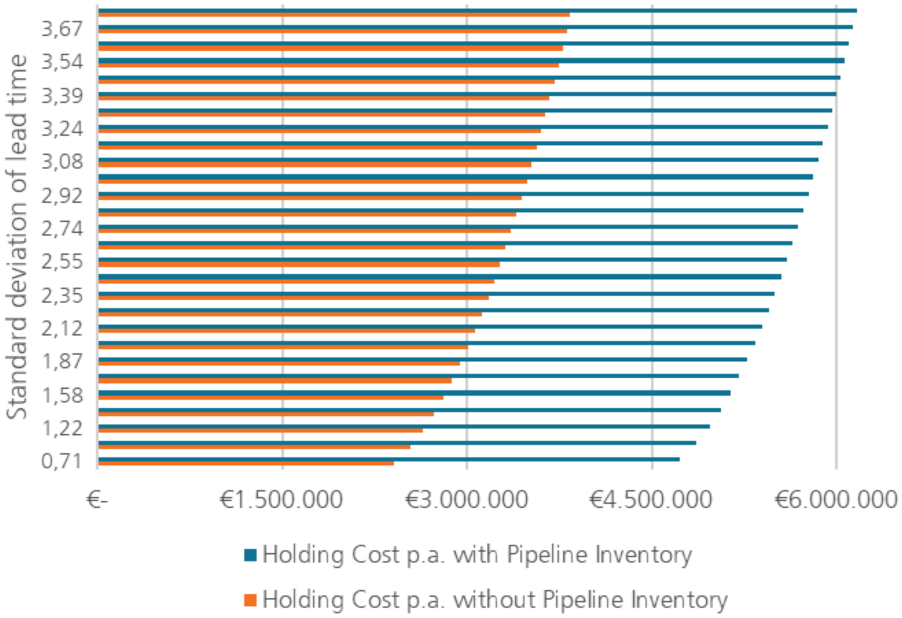


*Figure 5: Average Supply Chain Inventories under varying standard deviation of lead time*

Figure 6: Inventory holding cost under varying standard deviation of lead time



## 3.4 The potential role of MASS in a modern supply chain

### 3.4.1 Supply chain considerations – the MASS effect on service quality

Since the financial crisis of 2008 and until the beginning of the Corona pandemic in early 2020, cost has been the decisive criterion by which carriers have competed on the market.
This has manifested itself particularly in steadily increasing capacities of commercial ships and the associated economics of scale i.e., shipowners have tried to achieve cost leadership based on high transport volumes. In doing so, shipowners have increased efficiency and met customer demands for low prices and high availability of cargo space in that time (Kurt and Aymelek 2022).

In a recurring satisfaction survey (Drewry-ESC, Shipper satisfaction survey 2020,2021), shippers were asked about the most important criteria in carrier selection. As a result, the availability of cargo space, but also of equipment and price emerged as the most important criteria.
Other important factors are reliability, price stability as well as swift and accurate notification of the status of the cargo. The survey confirms the hypothesis already established in 2010 that the steady increase in complexity and the increased synchronization and integration of supply chains in recent years, is shifting customers‘ preferences away from price and further towards other factors derived from service quality (Stopford 2010).

Such factors are frequency of transportation services, accuracy of cargo tracking systems, transit time, consistency in providing customer service, error-free documentation, idle time of shipments, the transportation itself and overall responsiveness of the shipping service. (Yuen & Thai, 2015)

A defining factor that has gained importance in the recent past can be summarized under visibility  (IHS Markit 2022). About 80% of respondents indicated that increased visibility would have mitigated the impact of the pandemic on supply chains.

About half of the respondents are already working on implementing different solutions to increase visibility. MASS is a suitable basis for this, as the operation of an autonomous ship necessitates the generation and processing of large amounts of data in real time.

The resulting data can serve as the basis for various visibility solutions. These can then be used to provide reliable and accurate notifications to internal as well as external stakeholders, increasing visibility and customer satisfaction within supply chains. While Autonomous operation of vessels may have substantial effects on the aforementioned service quality criteria, it has to be noted that an important prerequisite for supply chain planning is the availability of accurate and timely information about the key performance indicators mentioned in 3.4.2. i.e., even the most thoughtful planning will fall short of expectations if the information it is based on is faulty or outdated.

A carrier using MASS could offer this data to its clients on top of the laid out quantitative differences in the cost structure between a conventional vessels and MASS and may therefore have a further competitive advantage over traditional maritime transport.

In the context of the recent pandemic, reliability and punctuality in liner shipping have both drastically deteriorated.

While in 2019 about 80% of port calls were still on time, in 2021 the figure was only about 36% (Sea Intelligence, Global Liner Performance report - 2021, 2022). Here, too, MASS promises to generate a positive effect. Algorithm-based dynamic route planning enables optimized reactions to deviations in the schedule due to, e.g., extreme weather events or congestion.

Possible delays are considered in the decisions of the autonomous system as well as current freight rates and fuel prices, which can effectively reduce variance in travel times without jeopardizing profitability. Furthermore, the decisions and the associated target variables, such as the ETA, are digitally available in real time, increasing transparency and enabling improved reactions by the stakeholders in the supply chain.

The increased plannability (i.e. lower variance) of port calls due to further standardization of port operations associated with MASS also facilitates the control of upstream and downstream processes and thus generally leads to more consistent value streams, which increases the overall performance of the supply chain. (Kurt and Aymelek, 2021)

A problem that increases proportionally with the size of the ships is port turnaround time, which has been rising/varying due to the increasing carrying-capacity and therefore larger maximum amounts of cargo to be (un-)loaded (UNCTAD review, 2021).

Since MASS facilitates the use of smaller vessels that, i.e., serve the routes with higher frequency, it can be assumed that turnaround times and thus the total travel time of goods will decrease, consequently having a positive effect on service quality.

Due to the increased frequency on routes served by MASS, both the flexibility of the shippers and the general availability of capacities increase.

As the average waiting time until the next shipping opportunity decreases, supply chains can be even more closely timed and better synchronized, while benefitting from

lower inventory holding costs (see 3.5.2). Frequency being a key factor in shippers perceived value, it has already been indicated in a study conducted by Puckett et al. (2011) in North-America and interpreted in favor for MASS' effect on service quality.
Nevertheless, the prominent failure of Maersks premium service 'Daily Maersk' in 2014 shows that this rationale also has its limits.

Since service preferences have significant impact on the perceived value which, in turn, has direct influence on the purchase intentions for shipping freight via short sea shipping, (Lin et al. 2021) the implementation of MASS appears as an opportunity to reduce operating costs while increasing service quality.
Thus leading to a win-win situation in which carriers improve their cost structure while effectively facilitating better supply chain management for their customers, directly affecting their financial bottom line – independently of transport cost.

### 3.4.2 Scenario I: A single Handy-size MASS

Under the given assumptions and estimations in this study, even for a single handy-size MASS cost savings could be realized in capital, operating and voyage cost on the carriers' side. Reductions are to be expected in, of course, manning, but also in stores, insurance, and fuel consumption and are not offset by any prospective increases in cost for port side operations and maintenance. Included RCC setup and operating costs pose as a minimum manning cost to be replaced in the single MASS.

This translates into a minimum crew- and therefore vessel-size to be substituted by a MASS in order to profit from the technology on a direct cost basis.

However, it has to be noted that in the case of a single MASS, the cost advantage compared to a single manned vessel is rather slim. Given the fact that the assumptions made in this study are based on estimations and expectations of industry and research experts, actual costs may differ to a certain extent. Additionally, there are many further peripheral costs to be considered, as changing processes, developing maintenance strategies and incorporating a single MASS in an existing, manned network, would be a challenge in and of itself. These peripheral costs largely depend on the structure and flexibility of the shipping company in question and are therefore difficult to estimate. With these costs in mind it is very likely, that while MASS is a technology that enables powerful economies of scale, it may be too expensive to introduce for a single vessel.

Direct cost aside, the analysis has also shown that, while there are still humans involved in remote supervision and control of MASS, the factor of human fallibility is expected to be greatly reduced in the midterm. With human error being the primary reason for naval accidents as well as for suboptimal routing and speed decisions it can be expected that the introduction of autonomous technologies has the potential to reduce disruptions and increase reliability of any oceangoing transport.
This means MASS technologies directly facilitate an increase in service quality, additional to the facilitation of increased visibility and the potential for associated value-added services.
With these parameters being key to the perceived value of transport services by ship-

pers, the attractiveness of a service using MASS may increase significantly.

This perceived value of shippers is of course founded in the implications for their supply chains:

Increased visibility allows for accurate and timely availability of KPIs - and therefore more accurate planning. A more reliable service then has direct impact on supply chain inventories and therefore on overall supply chain cost and efficiency by reducing uncertainty and freeing up of cash flows.

### 3.4.3 Scenario II: A fleet of MASS

Additionally, to the aforementioned expected effects of the substitution of a single manned vessel with a MASS on service quality, a fleet of MASS would enjoy proportionally larger savings in operating costs.
This is due to the mentioned strong economies of scale connected to remote-control centres (See 3.3.1.6).
This does in turn promote the use of smaller (standardized) vessels, as in the case of a fleet the total manning costs of said fleet compared to the RCC costs represent the main lower bound for a direct cost advantage.

While it cannot be estimated to what extent any cost savings would be passed on to shippers, this reduced cost may allow at the very least to gain cost leadership compared to manned vessels, which alone will increase profitability given independent freight rates. Should freight rates ever plummet back to pre-2019 levels, having lower cost than competing companies may very well decide the fate of a shipping company, as has been shown in recent years in an almost desperate war for capacity and the associated economies of scale in international shipping markets.

Further, it can be theorized that, with a need for much more standardized ships to support ease of remote-control operations, further economies of scale in ship ordering and building are facilitated and will result in an added reduction of capital cost contributing further to the overall competitiveness of the concept.

A fleet of small-scale MASS as a substitute for larger vessels in short sea shipping can not only realize high cost-efficiency but may also allow to substantially affect port operations (See 3.2.4.2).
More standardized port operations play into the ongoing automation of port terminals and may make true 24/7 operations more feasible, contributing to the rectification of prevalent port congestion, further improving the plannability and therefore the variability of port turnaround times.

Therefore, on the shipper’s side, operating a fleet of smaller MASS at a higher frequency has quantifiable effects on inventory management, while increasing flexibility and therefore resilience in the dependent supply chains (See 3.4.2).

# 4 Conclusion

**While the cost structures and developments of MASS in this study are based on a large amount of interviews and research (please refer to the full-length version of this study), it has to be noted that these expert opinions cannot replace empiric evidence.**
**While there is still an abundance of uncertainty in the market, the purpose of this study was to try and give the best possible estimate at this point in time, while showing the mechanics at work from a pure cost and service quality perspective.**

Nevertheless, it was shown that MASS has the potential for strong savings in capital, operating and voyage cost. At the centre of this hypothesis stands the substitution of manning costs by scalable remote-control centres unlocking economies of scale.

While this means that cost advantages for single MASS are comparatively minor, they become increasingly more powerful the more vessels are added to a fleet and managed in an RCC.
It can be expected that the greater the relation between crewing cost and overall ship cost in a conventional ship, the greater the effect of a substitution with MASS. Which suggests shortsea shipping as an ideal area of application from a cost perspective.

Very large MASS would nonetheless enjoy cost savings, but with crew sizes capping out around 30 on commercial ships the relative impact would be smaller.

On the other end of the spectrum, the cost of setting up and operating a RCC represents a bottom line, so using a very small autonomous inland vessel- to substitute e.g. a single barge normally operated by just one crew, is rather infeasible.

However, with a large enough number of very small MASS, the above statement still holds true.

In this regard further standardization in shipbuilding is promoted, as homogenous fleets would allow for more standardized remote control and supervision procedures, meaning fewer specializations and personnel are needed in the RCC.
Here, the prevailing hope is, that this need for standardized ships will lead to further reduced costs for shipbuilding in the long run as well, even though this questions the prospect of converting existing vessels.

Apart from cost, the analysis of service quality indicators in commercial shipping and their respective influence on their dependent supply chains demonstrated the potential for value creation on the shippers' side due to MASS.
Being able to provide KPIs more accurately, allowing for greater flexibility due to the facilitation of higher sailing frequencies, as well as offering the potential for greater reliability of a transport service, due to algorithmically optimized routing and speed decisions, has tangible effects on the cash flows of shippers and may therefore represent a direct competitive advantage.

The argument for greater reliability is also especially supported by the fact, that most naval disruptions are based in human error.

While marine insurers expect lower premiums in the mid- to long-term for this very reason, fewer maritime accidents will additionally help to further reduce the ecological footprint of maritime shipping and may even help to preserve endangered coastlines and reefs.

Nevertheless, the main reason for the lasting uncertainty concerning MASS is the distinct lack of regulatory frameworks for autonomous shipping in national as well as international waters.

Without clear guidelines on the allowed MASS-systems and their levels of autonomy in international and national waters, passages, and ports, companies will continue to find it difficult to create large use cases in good faith to their stakeholders.

However, these large use cases are needed to demonstrate the full potentials of MASS and to create the empiric data needed in order to come up with more accurate and reliable business cases.

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# 5 Opportunities for Cooperation with Fraunhofer CML

**Fraunhofer CML helps companies to close the gap between theoretical advances in maritime digitalization and practical application of research-based methods. Maritime safety and improved situational awareness of nautical shipping personnel are core topics of Fraunhofer CML.**

**Additionally, Fraunhofer CML has substantial experience in building AI solutions for data-based predictions and decision support systems in maritime logistics from proof-of-concept to implementation.**

Solutions are specifically tailored to the requirements of the maritime industry and individually tailored to the needs of each customer. In addition to a wide range of international and national contacts, Fraunhofer CML has the opportunity to draw on available resources of the Fraunhofer Gesellschaft within its projects.

With strong expertise in MASS technologies and its economic assessment, Fraunhofer CML is the optimal partner to support companies in adapting new technologies. Fraunhofer CML conducts feasibility studies for public and private partners on autonomous watercrafts and ships, determining the demand for transport in various market segments and assessing cost and economic benefits.

By applying smart and innovative methods of data collection and evaluation such as machine learning and mathematical optimization while following a business management approach, Fraunhofer CML provides future-oriented solutions that go beyond the state-of-art. With the model presented in this extended study outline Fraunhofer CML can evaluate and optimise your logistic use case in a similar form.

As an active research partner in multiple projects Fraunhofer CML is not only up to date with the latest developments in virtual and augmented reality, verification of AI algorithms, advanced decision support systems, or automated monitoring and maintenance in a maritime context, but also actively drives the development of those innovations forward. Fraunhofer CML offers solutions for digitalization and automation along the whole maritime logistics chain with a distinct focus on MASS technologies and innovations.

Furthermore, Fraunhofer CML has vast experience in ship simulation, onshore training as well as risk assessment of nautical manoeuvres and port infrastructure studies to support customers needs in adapting to upcoming developments such as remote controlled and autonomous ships.
With its research in maritime simulation Fraunhofer CML aims to increase efficiency and safety of ship navigation.

Fraunhofer CML partners with Novia University of Applied Sciences and Aboa Mare in Turku, Finland in a joint research platform called "Fraunhofer Innovation Platform for Smart Shipping at Novia University of Applied Science", short FIP-S2@Novia.
The joint research addresses smart systems in navigation as well as maritime digitalization. The cooperation benefits from Novia's wide expertise in maritime training and simulation. Future joint research projects will aim, among other topics, to develop and transfer novel VR applications in maritime navigation and training into practice.

Since its founding in 2010 Fraunhofer CML has proven to be a valuable research and development provider for companies as well as for national and international research projects.

With more than 10 years of experience Fraunhofer CML continues to support companies and institutions from shipping, port management, and logistics in initiating and implementing future-oriented technologies and processes.

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