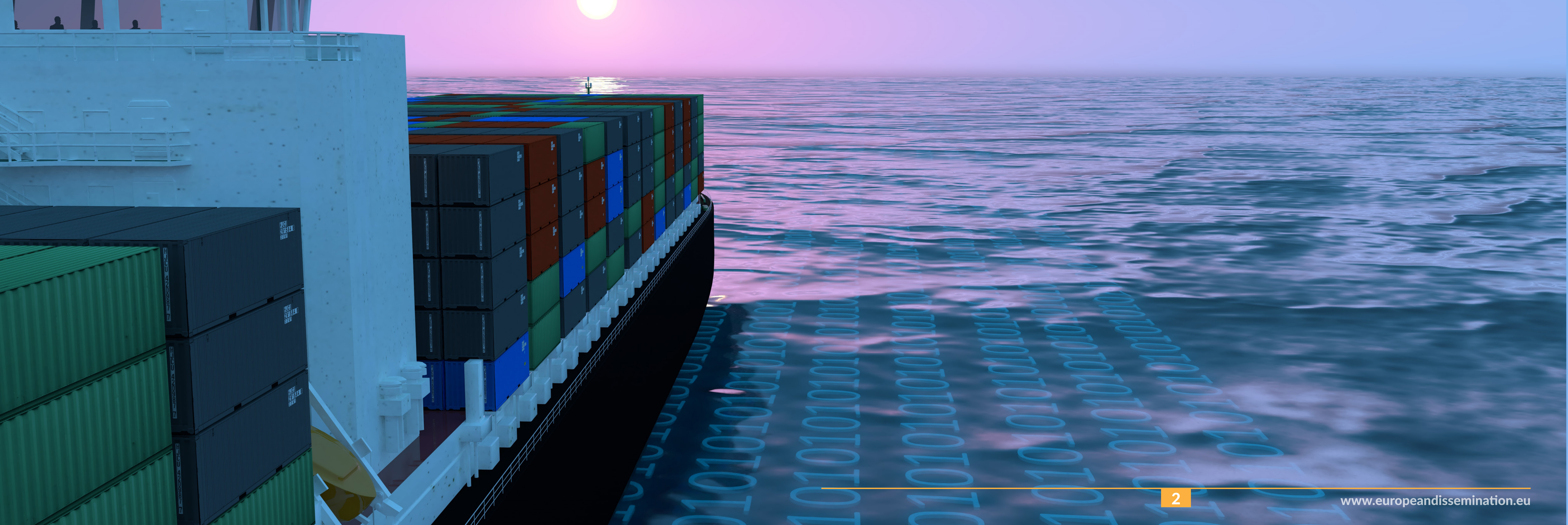
DISSEMINATION
The AUTOSHIP project

The AUTOSHIP project: speeding-up the transition towards a next generation of autonomous ships in the EU

Contents



1. AUTOSHIP project

Although Asia has dominated the shipbuilding industry for several decades due to lower-cost manufacturing, Europe has maintained a leading market share in specialised, high-quality vessels. Supported by the industrial and technological expertise of leading European maritime companies, the EU-funded AUTOSHIP project – Autonomous Shipping Initiative for European Waters (Grant Agreement N°815012) – aims to build and demonstrate two self-navigating ships and their shore control centres as a prototype infrastructure to develop a fleet of next-generation, autonomous vessels, speeding up the transition towards the next generation of autonomous ships in the EU.

More in detail, since 2019, AUTOSHIP has been developing key enabling technologies (KETs), installing them on two existing vessels (Figure 1) and preparing to demonstrate remote and autonomous (R&A) operations, including the needed shore control and operation infrastructure. The demonstration level eventually reaches and exceeds Technology Readiness Level (TRL) 7.

In 2023, the final tests will take place during two pilot demo campaigns, including one from the Norwegian to Danish waters and one in the Flemish waters, which are among the areas most relevant to the EU waterborne transport market.

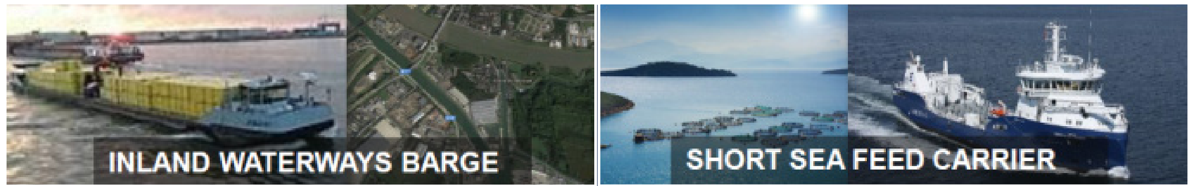
The demonstrators will help ship operators and owners to measure and improve economies of scale in their autonomy investments. In turn, waterborne transport will be supported in gaining competitiveness, possibly generating momentum to renew outdated fleets and increasing their competitive ability to replace road transport, where this is still the more reliable/cheaper alternative.

The technology package includes autonomous navigation (e.g. via awareness and object detection), self-diagnostics, prognostics and operation scheduling, and communication technology enabling a prominent level of cybersecurity and integrating the vessels into upgraded e-infrastructure. In parallel, digital tools and methodologies for design, simulation and cost analysis have been and will be developed for the whole autonomous ships industry.

The project is generating evidence that autonomy can reduce costs and improve the overall efficiency onboard (less fuel and logistic procedures) thanks to advanced technology for monitoring, data fusion and communication with a more evolved network. Interoperability and the internet of things (IoT) can also increase every operation's safety, security and speed, provided that a robust cybersecurity shield is realised.

The use cases developed within the project will optimise efforts and investment, while the project is also working to advance common standards and enable operations in a shorter timeframe than expected: this will allow commercial applications of the technology behind the next generation of autonomous ships after 2023.

Further in this ebook, we will discuss autonomy in shipping, current initiatives and the main stakeholders. We will also bring to light how AUTOSHIP supports autonomous shipping to overcome technology development and safety challenges.



Operational focus	Transit, docking and unlocking, lock navigation, continuous operation	Transit, docking and unlocking, cargo operation, fish farm interaction, weather window
Autonomy level	4. Constrained autonomous and continously unmanned	3. Constrained autonomous and periodically unmanned bridge – high degree of automatic operations
Area of operation	Inland waterways	Open Sea
Rules & regulations	National authorities and local governing bodies	Flag state, classification societies, IMO
Shore operation	Logistical and transport planning, monitoring, exception handling	Route planning, monitoring, remote controlled operations, exception handling, decision support
Infrastructure	RIS (River Information System), VTS, lock interaction	Local / Coastal VTS
Connectivity	Near land possible use of mobile networks and shorter range communication	Shorter range communication where available, otherwise satellite communications

Figure 1: AUTOSHIP remote and autonomous vessels.

2. Why Autonomous shipping?

Why do we want to make waterborne transportation more attractive and competitive?

In short, truck transportation appears to be the least sustainable form of transportation, while waterborne transportation is the most sustainable in terms of external costs, although rail transport falls somewhere in between. We will get back to a quantitative comparison of the social impact of transportation modes shortly, but first, we need to define external costs:

> **External costs** are the costs incurred by a third party because of a transaction of which the third party is not a part (i.e. costs related to externalities such as climate change, emissions and air pollution).

Transportation causes negative impacts on society, and the comprehensive study in [1] provides estimated quantifications in monetary terms of these impacts (external costs). The societal impacts, or external costs, considered in [1] are accidents, air pollution, climate change, noise, congestion (in terms of delay costs), well-to-tank, and habitat damage. Each external cost category is estimated as a cost per tkm[1], for each EU28 country[2], and as an average for the EU28 countries.

If we consider the external cost estimates in [1], given in Figure 2, we clearly see that freight transport by trucks causes the highest external costs.

One might think that the onset of electric trucks could radically change this picture; however, as we see in Figure 2, trucks cause significant external costs in

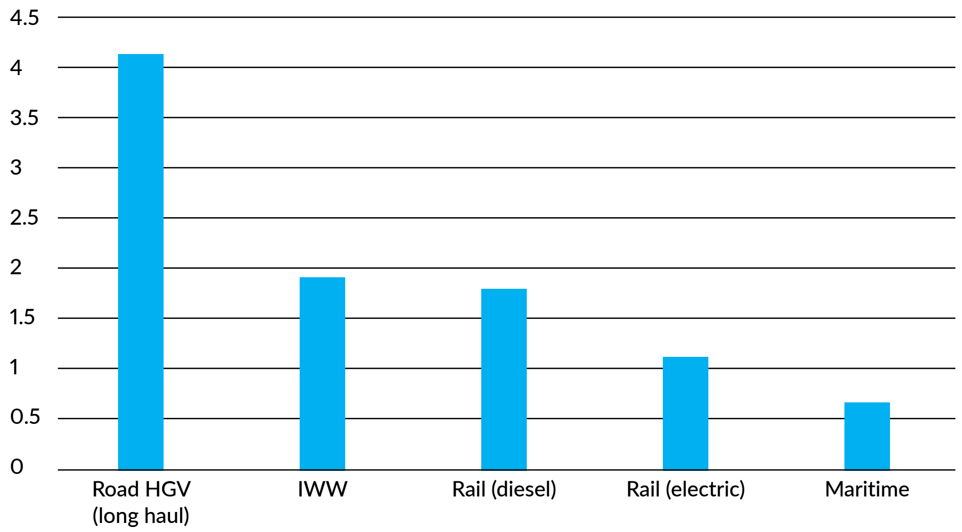


Figure 2: Average external costs of transportation for the EU28 countries in €-cent/tkm. Data from [1].

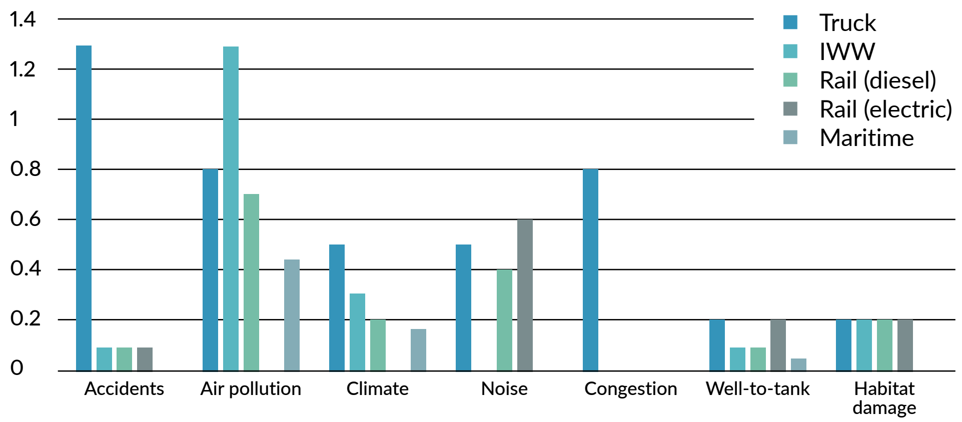


Figure 3: External costs of transportation per category for the EU28 countries in €-cent/tkm. Data from [1].

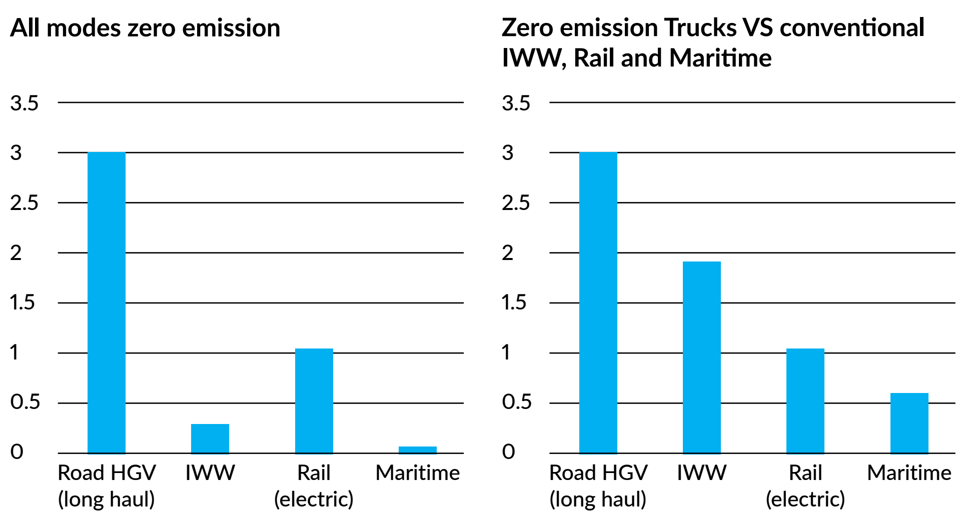


Figure 4: All modes zero emissions, to the right: Zero-emission Trucks vs IWW, Rail and Maritime transportation as is today.

1 tkm, or tonne kilometre, is a measure of transportation work: transporting 1 tonne for 1 kilometre.
2 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:EU_enlargements

categories unrelated to greenhouse gas emissions. This means that if we compare zero-emission trucks to the other transportation modes as they are today, as seen in Figure 3, we find that the external costs of trucks are still considerably higher than for other transportation modes. Furthermore, waterborne transportation is also moving towards zero emission, which means that in an emission-free transportation future, the relative difference in external costs between truck and waterborne transportation will be ever larger, as seen to the right in Figure 4.

Thus, working for zero-emission transportation solutions for all modes of transportation is very important. As we see from the external cost estimates, it is also important to reduce overall truck transportation to reduce societal costs, regardless of future developments concerning zero-emission solutions. This is why moving transportation from road to water is attractive and why we want to make waterborne transportation more attractive and competitive.

Why autonomy?

Autonomy (with different degrees of application) is not a target on its own, but it can support the challenges of the shipping business in different ways.

Firstly, it can answer the challenge concerning the shortage of seamen [3], [4], [5], and improve safety even if the number of accidents is not reduced [5].

Autonomy is interesting in an economic context due to the possibility of reducing onboard crew. Consequently, the reduced operational costs make waterborne transportation more competitive: taking the AUTOSHIP Short-Sea Shipping (SSS) demonstrator as an example (see Figure 1), the annual crew-related costs are approximately 1.2 million Euros.

Current commercial projects also show that autonomy can unlock new services and use cases that would otherwise not happen; this will evidently generate positive externalities in terms of societal sustainability. With no humans onboard, ships can be designed entirely differently: an accommodation section would no longer be needed, along with a range of equipment intended for the safety and comfort/needs of humans. This makes it possible to carry more cargo and to optimise the hull design for minimal power consumption, only considering the integrity of the ship and the cargo. Furthermore, [2]removing accommodation and crew-related equipment and systems will result in reduced power consumption [2] and construction costs.

Reduced operational costs and no- or limited crew also provide increased flexibility regarding operational times, durations, areas and sailing speeds. Smaller ships could become economically viable, increasing the number of ships in the fleet and thus improving flexibility. If a ship becomes unavailable, the impact on the fleet capacity is smaller, improving resilience. Accidents or incidents (such as the Ever Given) would have less significant consequences.

In sum, autonomy will increase the competitiveness of waterborne transportation relative to trucks. In addition, it can reduce emissions as the power consumption per freight work (tkm) will be reduced due to increased cargo capacity and more efficient designs. [3][4][5]

3.
Who are the players currently shaping the innovation scenario? What are the most interesting initiatives and their objectives?

During the project, an intense effort was made to consider relevant stakeholders' views on autonomy [6]. A mapping of these stakeholders was completed beforehand based on specific methodologies for technology and market intelligence [7].

In this section, we report the key findings of a comprehensive updated mapping of privately and publicly funded initiatives and their respective players. A mixed point of view has been considered, which has evidenced the steep growth and momentum for autonomy in the maritime business worldwide (Figure 5).

Commercial (privately funded) initiatives

During its intelligence collection, the partner PNO has found evidence of **43 commercial projects focusing on freight transport and the maritime supply chain**. They are presented here, mapped (Figure 6) and categorised based on their assumed technology readiness at

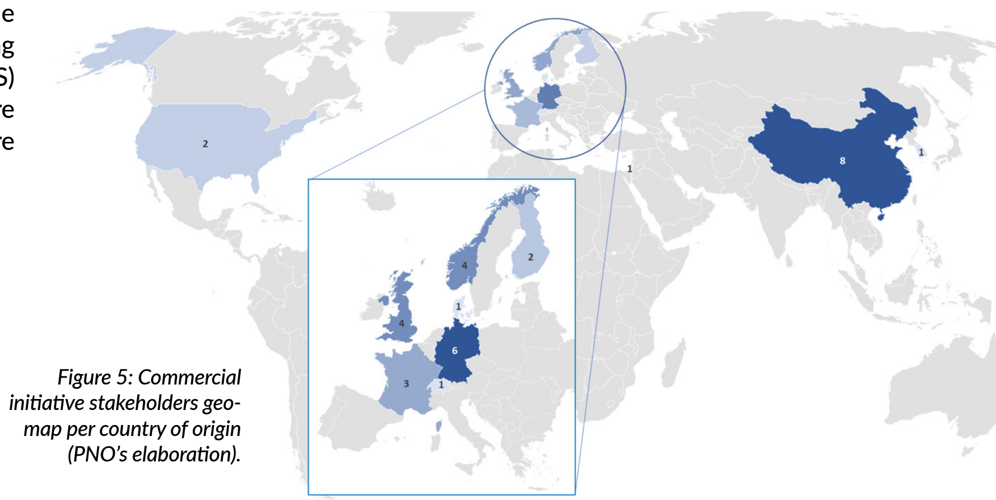


Figure 5: Commercial initiative stakeholders geo-map per country of origin (PNO's elaboration).

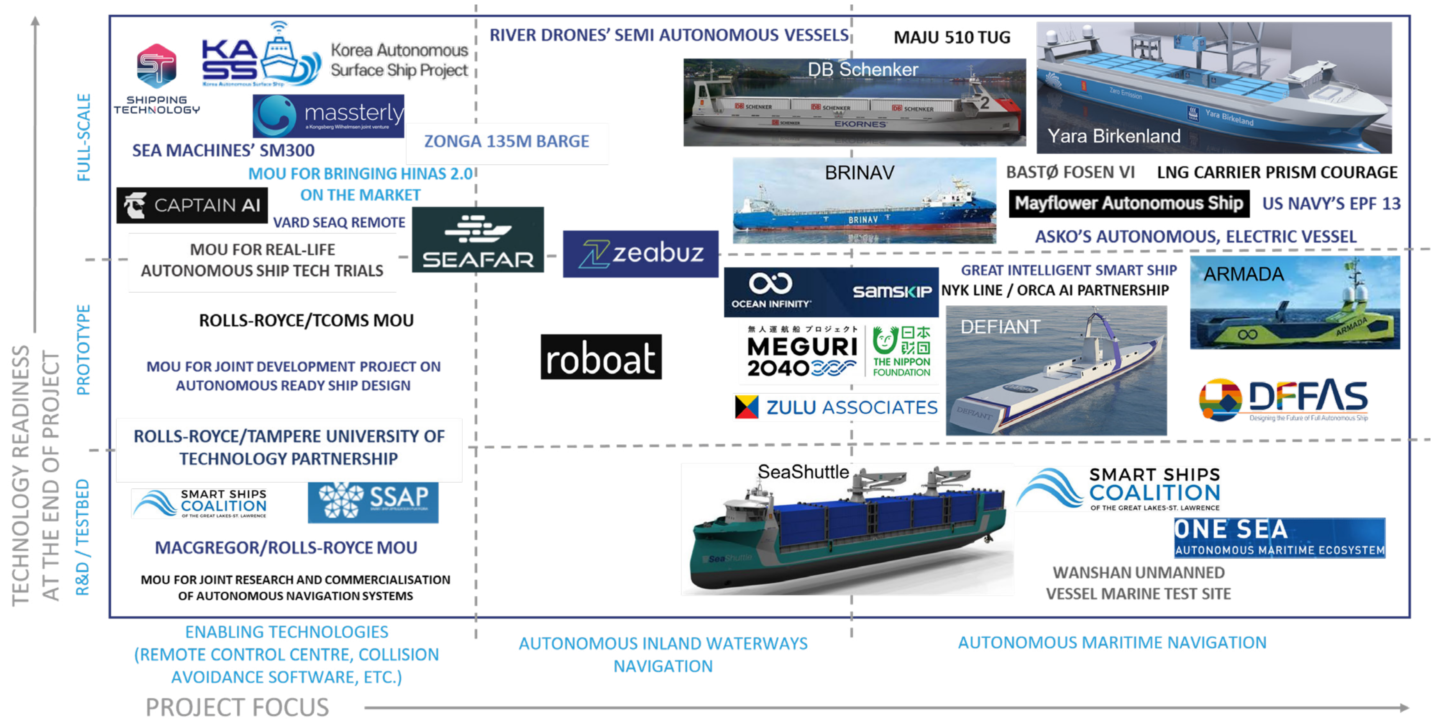


Figure 6: Commercial Projects Mapping (PNO Consultants elaboration).

the end of the project (R&D or testbed, prototype, full-scale) and their purpose: whether this was the development of enabling technologies (remote control centre, collision avoidance software, etc.) or the realisation of specific applications for maritime and inland vessels.

International and deep-sea cases

In short, commercial initiatives for autonomy in deep-sea shipping are few and mostly focused on decision support for the onboard crew. There are some commercial technology demonstrators outside the EU, and some have signed contracts for delivering their products to newbuilds.

In the APAC region, Korean Register (KR) will be closely collaborating with Hyundai Heavy Industries (HHI) and its subsidiary Avikus as well as the Liberian Registry (LISCR) to commercialise autonomous navigation technology. The four parties signed a Memorandum of Understanding (MoU) at HHI's headquarters in Ulsan, Korea, on 26 August 2022, to collaborate on bringing the Hyundai Intelligent Navigation Assistant System (HiNAS 2.0) to market. This year, the company completed the world's first transoceanic voyage of a large LNG carrier relying on autonomous navigation technology.

HiNAS 2.0 will be next installed on KR-classed and LISCR-registered ships in July 2023.

NYK has been working to establish the technical and operational benefit of maritime autonomous surface ships (MASS) in the last years, to enable remote and unmanned navigation, answering crew shortage challenges. In September 2019, NYK conducted the world's first MASS trial performed by the IMO's interim guidelines for MASS. The tests have been evaluating their technology package, Sherpa System for Real ship (SSR), which is a navigation system for calculating optimal routes as decision support to the crew. The trials conducted on 14–17 September 2019 and 19–20 September 2019 monitored the SSR's performance while it calculated collision risk, optimal routes and speeds and automatically navigated the ship.

Less than three years later, the DFFAS (Designing the Future of Full Autonomous Ship) consortium is participating in the Joint Technological Development Programme for the Demonstration of Fully Autonomous Ships under the fully autonomous ship project "MEGURI 2040" launched by The Nippon Foundation in February 2020.

From 26 February to 1 March, DFFAS conducted a successful trial simulating the actual operation of the fully autonomous ship Suzaku by having the vessel sail a distance of approximately 790 kilometres between Tokyo Bay and Ise Bay, including offshore manoeuvring, bay navigation, coastal navigation and berthing manoeuvring, using a comprehensive fully autonomous navigation system (i.e. the DFFAS system).

In the US, the international classification society American Bureau of Shipping (ABS) verified the design of a Foss harbour tub outfitted with an autonomous self-piloting system supplied by Boston-based Sea Machines Robotics. The Foss tug Rachael Allen will first leverage the SM300 system, the company's flagship commercial product, which is a major advancement in bringing autonomy to the marine supply chain. The Foss harbour tug will use this system for routine transit and stand-by operations before trialling remote piloting from a shore-based command centre. The SM300 transit autonomy and station keeping are provided by interfacing with the Norwegian Kongsberg-MTU's propulsion system controls.

Figure 7: Top companies emerged from Commercial projects (PNO Consultants elaboration).

Short sea

Several ongoing commercial initiatives exist for remotely controlled and autonomous unmanned shipping in SSS. Projects addressing autonomous vessel technology have been developed with a vibrant core in Norway and Germany. A common denominator is that these initiatives are driven by the shipping companies' targets for sustainability, with reduced or zero emissions, and that a stepwise approach towards autonomous shipping via crewed, and later uncrewed, remotely controlled ships, is planned.

Norway and Northern Europe are at the forefront of the latest EU announcement of autonomous freight vessel services, which cargo owners promote: Yara and ASKO to name the most well-known.

Yara Birkeland is already in commercial operation, while ASKO's sea drones have entered a two-year trial (learning from their reduced crew) period, after which they will go completely unmanned.

These three ships are all electric and have received considerable public funding through ENOVA grants for reducing CO_2 emissions by replacing truck transportation with zero-emission ships. Another commonality for these three ships is that Kongsberg Maritime AS and Massterly are technology providers and operators respectively. These companies are therefore leading the race to supply the KETand services to autonomous short-sea transportation ships.

Moving to the Netherlands, two other ships are in the pipeline. Samskip has partnered with Ocean Infinity and secured funds to build two 500TEU hydrogen-powered, remotely controlled and autonomous-ready containerships for delivery by 2025. They have received a 150m NOK grant from ENOVA to build the ships that will operate between the Oslo Fjord and Rotterdam.

Finally, one zero-emission autonomous short-sea container ship was announced as DB Schenker, Ekornes, Naval Dynamics, Kongsberg Maritime AS and Massterly signed a pre-study agreement. The ship is intended to operate in the dedicated supply chain for the cargo owner Ekornes and will be of the NDS AutoBarge design, the same design used by ASKO. While the timeline for design, construction and operation is unknown, this is yet another commercial initiative employing autonomy to achieve unmanned short-sea transportation.

RCCs are expected to be an important part of autonomous ship systems infrastructure for the foreseeable future. Thus, all the discussed short-sea initiatives have Massterly or Ocean Infinity as remote control centre (RCC) operators, with Massterly being involved in most of the current projects.

Massterly and Ocean Infinity have opened their first RCCs within the Armada project, which concerns the construction of a fleet of 23 robotic vessels. Massterly is also already in the commercial operation phase for the Yara Birkeland, while Ocean Infinity conducted the first remote operations demonstrations in June 2022. The company streamed the data collected, using satellite communications from the ship's location directly to Ocean Infinity's RCC in Southampton, UK.

Given the ongoing initiatives' maturity, it appears that commercial uncrewed autonomous SSS is emerging from the short to medium-term perspective. Notably, these are also important steps towards international and intercontinental autonomous shipping.

Inland waterways

Inland waterways are strategic for the EU since they are a great resource for moving goods from road to water in a large area of Europe, from west to east. Besides, autonomy is an asset to improving overall infrastructure resilience.

To develop autonomy, though, it is most likely that new intermediaries (such as RCC operators) are needed to provide services and share costs in a sustainable way. In this context, the technology and services company SEAFAR has already made semi-autonomous sailing a reality by controlling ten ships from a control room in Antwerp and is planning similar facilities in Namur and Dordrecht. Since March 2021, SEAFAR received additional permission to operate at night and test without crew on board but with full control

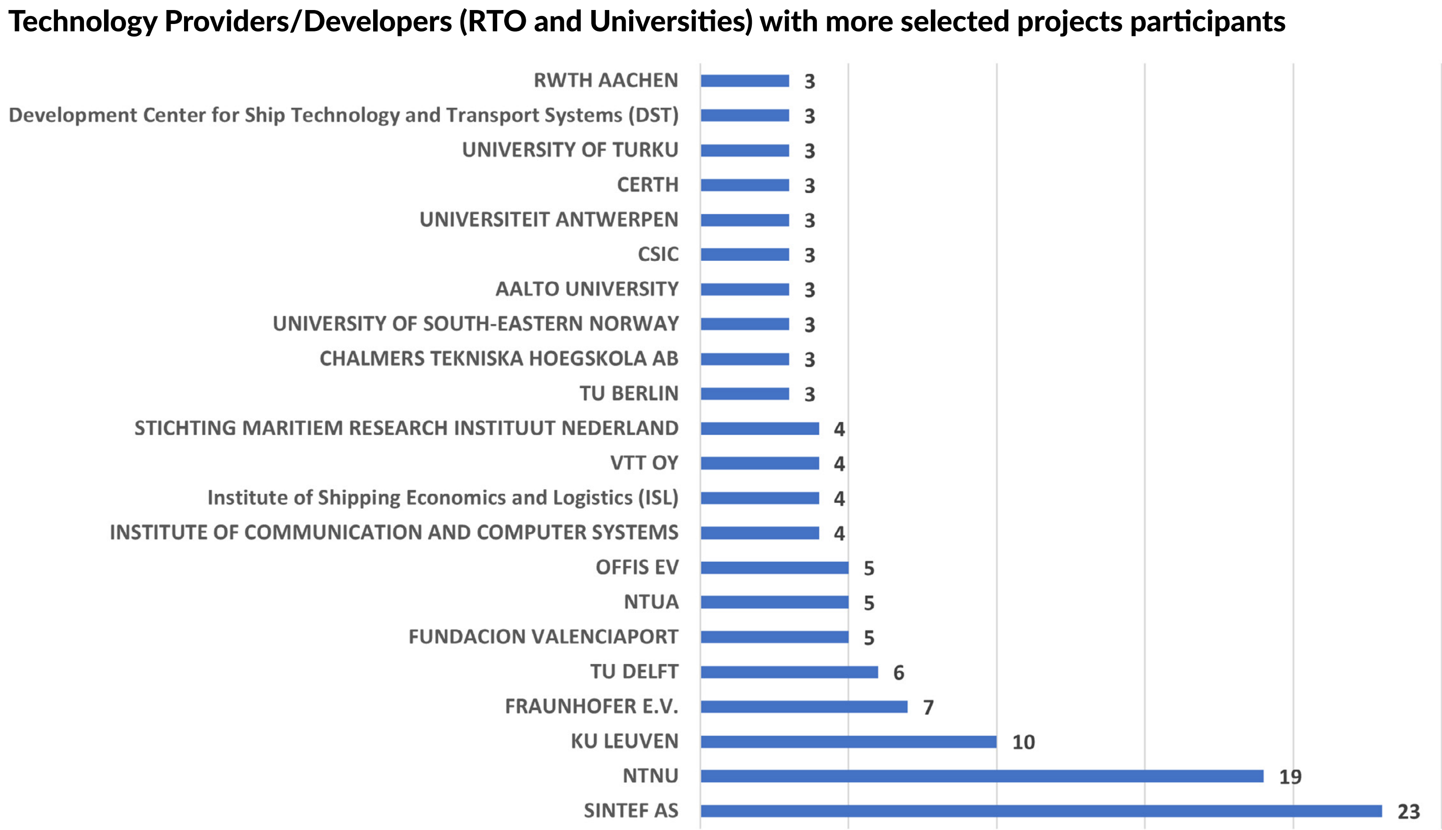


Figure 8: Most active organisation in terms of R&D projects participation (PNO Consultants elaboration)..

from the SCC. SEAFAR's captain directs ships remotely from a control room. They steer up to three ships at a time, and 80 per cent go autonomous, with only a few crew members remaining on board. In the meantime, SEAFAR's partner Alewijnse offers a comprehensive package of technical solutions that includes full electrical installations, systems for energy distribution, generation and propulsion, process automation, audio, video and ICT and systems for safety, navigation and communication. On 18 October 2021, the test was extended for another year.

AUTOSHIP partner Zulu Associates is acting as an initiator, developer and operator of innovative vessels in marine and inland waterways logistic chains. Its goal is to enable the zero-emission operation of commercial vessels on inland waterways, short-sea and coastal routes through autonomous operation and alternative propulsion. After managing the Pullet Shuttle Barge under testing in AUTOSHIP, Zulu Associates are developing new models of autonomous barges which allow full exploitation of the new designs (smaller, more flexible, green ships) while exploring new business models to cut the additional costs for low to zero-emission propulsion. The first in the series is the X-Barge, a CEMT class 4 barge. The aim is to prove that this type of vessel can operate on the Rhine in 2023 and to obtain the permit for permanent uncrewed commercial operation. Some public funding has already been secured as Zulu will keep testing its technologies in the next generation of EU-funded projects starting in 2022 and 2023.

The R&D and innovation arena

Funding and collaborations

On top of commercial initiatives, we have looked for the mid-to-long-term scenario of autonomous shipping in 108 R&D projects focused on maritime transport or maritime logistics operations, started after 2010, and funded by the European Commission or other European national entities. Of these projects, 42 belong to various programmes funded by the European Commission with around €207 Million, 40 are funded by Norway with ca. €38 Million, and many others are funded by different European national states with ca. €27 Million.

The network in Figure 9 shows different sub-ecosystems with slightly different and synergic objectives.

At the core of the ecosystems network, we can find organisations working on the development of e-navigation and e-infrastructure technologies or other digital tools enabling autonomous navigation. The left side of the figure shows the organisations that work primarily on the development of autonomous transport in inland waterways and it is worth noting that this mini ecosystem is mostly made up of German and Belgian organisations.

The upper right part of the figure shows small ecosystems focused on the development of autonomous navigation for freight transport through the digitisation and automation of ports, developing smart logistics though the entire supply chain.

3 Belgium, Netherlands, France, Germany, Norway, Finland and the United Kingdom.

Networking of the selected funded projects

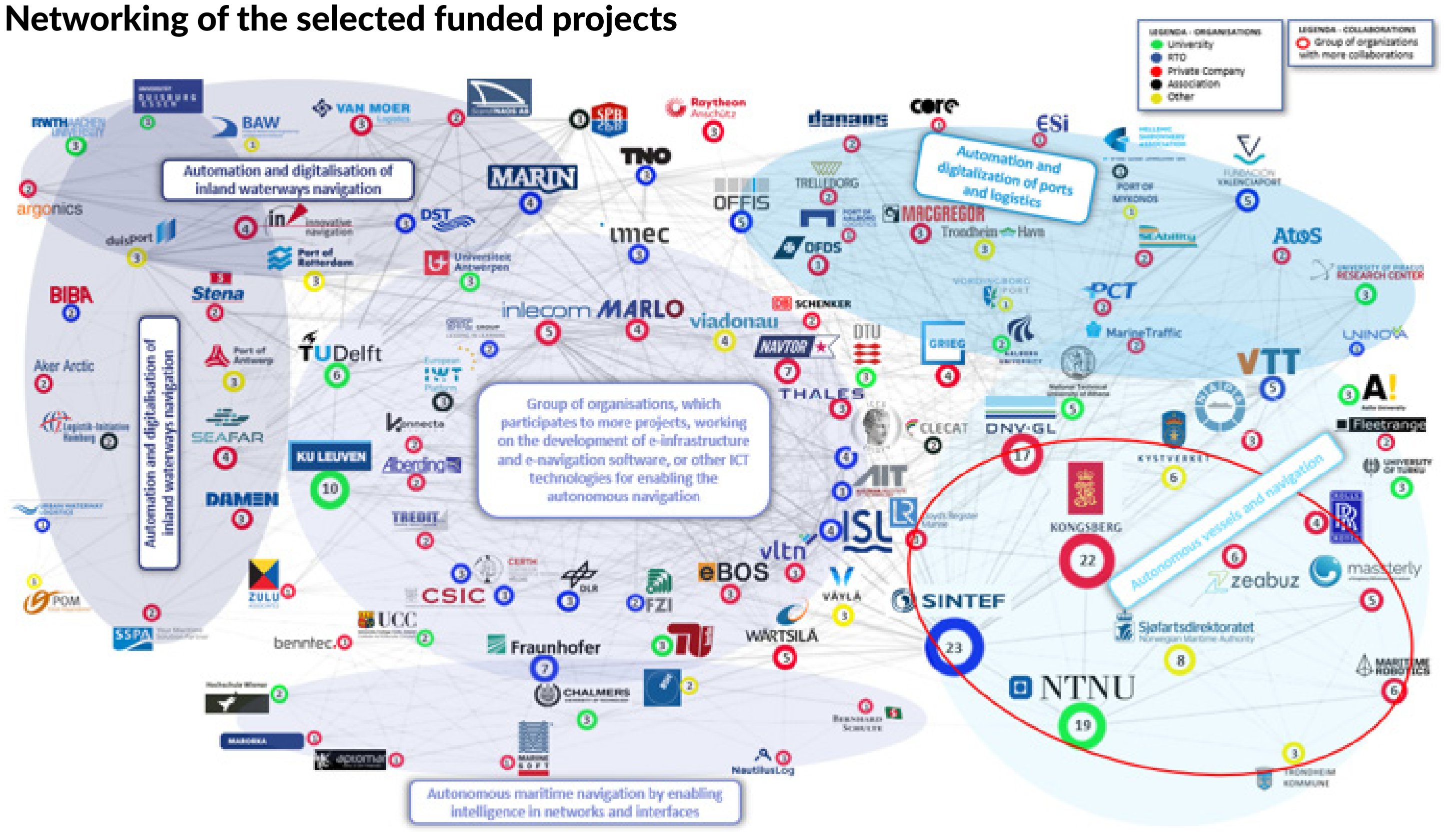


Figure 9: R&D network map showing projects and related partners and cooperations (PNO Consultants elaboration).

The network in Figure 9 shows different sub-ecosystems with slightly different and synergic objectives.

At the core of the ecosystems network, we can find organisations working on the development of e-navigation and e-infrastructure technologies or other digital tools enabling autonomous navigation. The left side of the figure shows the organisations that work primarily on the development of autonomous transport in inland waterways and it is worth noting that this mini ecosystem is mostly made up of German and Belgian organisations.

The upper right part of the figure shows small ecosystems focused on the development of autonomous navigation for freight transport through the digitisation and automation of ports, developing smart logistics though the entire supply chain.

Finally, the last sub-ecosystem, shown on the bottom right, focuses on the development of real autonomous vessels and autonomous navigation demonstrations. This ecosystem mainly includes Norwegian and Finnish organisations and contains the key players developing autonomous navigation. Here we can find not only the organisations with more project participation but also those with more collaborations between them (marked by the red line). They are SINTEF, Kongsberg Maritime AS, NTNU, DNV, the Norwegian Maritime Authority, the Norwegian Coastal Administration, Zeabuz, Masstlerly and Maritime Robotics, who have a prominent positioning, having collaborated in at least four projects.

Start-ups ecosystem related to autonomous shipping

Figure 10: Start-ups ecosystem related to autonomous shipping (PNO Consultants).

All in all, we can see progressively larger and more integrated projects where autonomous technology seamlessly connects to cargo owners, smart ports and longer value chains. Passenger use cases (e.g. ferries) are also included. This integration can eventually provide the optimal definition of the autonomous/smart shipping market and the set up of agreed business models. Furthermore, autonomy is being included in resilience and sustainability cases.

As a recent example, under the lead of the European Inland Waterway Transport(IWT) Platform, 24 important European stakeholders in water transport, including SINTEF, SEAFAR, ZULU Associates and others, have set the ambitious target of playing a key role in the ReNEW project: supporting the transition of IWT to the smart, green, sustainable and climate-resilient sector, promoting economic growth. The project aims to minimise both the negative impact on the environment and the significant and lasting degradation of ecosystems through zero-emission transport. To achieve this, the ReNEW will build on previous results, capitalise on cooperation opportunities with ongoing projects and initiatives, and is expected to introduce different sizes of automated multipurpose vessels and their infrastructure by 2025.

The autonomous ship market thrives both with large industries leading the market, like Kongsberg, and with smaller players providing breakthrough digital solutions and AI. From the analysis, 47 worldwide start-ups (Figure 10) founded since 2014 were selected:

- nine of them come from the USA; six from UK, Norway and Netherlands; three from South Korea and Germany; two from Finland, Belgium, France, Japan and Israel; one from China; one from Brazil; one from Australia; and one from Spain.
- two were founded in 2022; four in 2021; five in 2020; six in 2019; ten in 2018; nine in 2017; six in 2016; two in 2015; and three in 2014.

As a proxy of private capital behind autonomy, for all these start-ups, we have tried to identify the amount of received funding, where possible. SenseTime seems to have the record here, having reached about $5.2 billion. However, it must be considered that this start-up operates, for the most part, in the automotive sector. SenseTime is followed by Sea Machines Robotics, which has received total funding of almost $30 million, ShipIn Systems with $24.8 million, and Orca AI with $15.8 million. Some of them have also emerged from the public funded projects analysis: Masstlerly AS, Zulu Associates, Sea Machines and Automated Ships Ltd.

Market and innovation positioning

The Market & Innovation Positioning Map (MIPM©) is a four-quadrant matrix defined by PNO in the last eight years (Figure 11). Its advantage is that it is built in such a way to particularly:

1. define the general framework of noticeable companies working on a particular technology topic
2. evidence those key—smaller/emerging—players with very specific knowledge of the analysis subject matter.

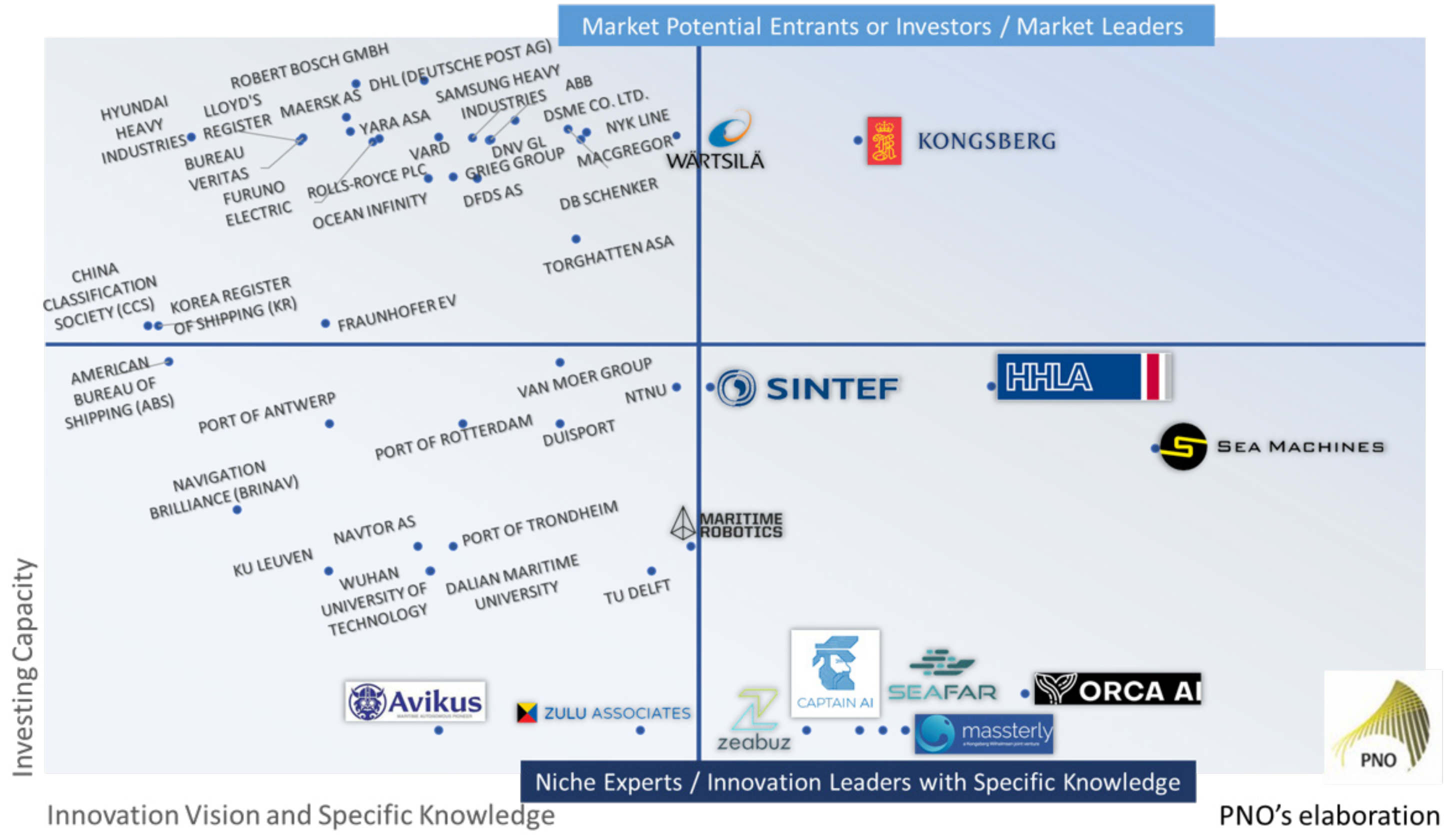


Figure 11: AUTOSHIP MIPM (PNO Consultants' elaboration).

The analysis is intended to be qualitative but based on a quantitative weighted measurement of a mixed scoreboard.

Organisations with growing investment capacity are positioned from the bottom to the top. Organisations with increased specific domain knowledge and innovation are positioned from left to right. Therefore, the upper right quadrant defines organisations most likely to be market incumbents/entrants, while in the lower right quadrant, relevant technology providers or 'visionaries' can be found, having the most specific knowledge concerning the analysed topic.

For the AUTOSHIP project, the MIPM is a snapshot that identifies the 'position' of an organisation with respect to the development and application of autonomous and intelligent/smart technologies for the maritime navigation and smart logistics sector (e.g. ports, terminals, etc.).

The market and technology leader, shown in the upper right quadrant, in the autonomous shipping sector is:

- Kongsberg Maritime AS. Kongsberg and its various subsidiaries are the leading European group for dynamic positioning and navigation, marine automation, safety management, cargo handling and other intelligent technologies for the maritime sector. Its position in the sector was further strengthened with the acquisition of Rolls-Royce Commercial Marine (RRCM), completed in 2019; also a pioneer in the introduction of autonomous technologies for maritime navigation, especially for autonomous vessels.

The top-left quadrant shows the potential entrants or investors. The closest potential entrant and challenger appears to be:

- Wartsila, a leading provider of electronics and automation systems for the marine sector. Wartsila have been focusing more and more attention on providing automation and autonomy systems for commercial vessels in recent years.

Innovation leaders are shown in the bottom right quadrant; they develop AI-based enabling technologies and suites for control and remote operations for autonomous vessels.

- Sea Machines Robotics, a US-based SME founded in 2014, is the lead provider of advanced technology for the maritime sector, with a product line of autonomous control and navigation systems for commercial boats and ships. They have already received a remarkable amount of private funding.
- ORCA AI is an Israelian start-up combining computer vision and deep learning technologies with existing onboard sensors to enhance the situational awareness of onboard crews, reduce sensory information overload and enable better navigation decisions.
- Massterly AS is a Norwegian start-up born as a joint venture between Kongsberg Maritime AS and Wilhelmsen. They are one of the world's first companies to operate autonomous vessels by using a shore control centre in Norway. They offer services to the entire value chain of autonomous ships, from vessel design and approval to control systems, logistics services, vessel operations, insurance and possible assistance with financing.
- Seafar NV, a Belgium-based start-up, develops solutions and offers services to operate unmanned and crew-reduced vessels for inland and short-sea ship owners and shipping companies via its control centre located in the port of Antwerp.
- CaptainAI, a Dutch start-up located in the port of Rotterdam, develops a safe and fully autonomous shipping solution using high-fidelity simulation, cutting-edge sensors and state-of-the-art deep learning techniques.
- Zeabuz AS, a start-up spinout from the Norwegian University of Science and Technology (NTNU) which provides Autonomy as a service to urban ferry operators.

In addition to these emerging companies, more structured and experienced organisations in the sector also appear in the lower right quadrant.

- HHLA (Hamburger Hafen und Logistik AG) develops logistical and digital hubs and currently operates a dense network of maritime port terminals around Europe.
- SINTEF, the Norwegian RTO specialising in autonomous transport systems and digital technologies for maritime sector.

The bottom-left quadrant includes the core of R&D and industrial experts when it comes to systems and technologies related the autonomous shipping and maritime logistics sector. Among them, some companies deserve particular attention as they could definitely switch to the right side of the map in the next future.

- Maritime Robotics AS, a Norway-based SME which provides innovative unmanned and autonomous vehicle systems.
- Zulu Associates, a Belgian start-up which is active as initiator, developer and operator of innovations in commercial vessels on inland waterways, short-sea and coastal routes through autonomous operation and alternative propulsion. Zulu is also connected to a constellation of related companies and subsidiaries which use its innovative technologies, like Blue Line Logistics NV (sold to Sogestran Group), the Anglo Belgian Shipping Company LTD, Zulu Associates America LLC and Continental Inland Navigation Company.
- Avikus, a start-up company specialising in developing autonomous navigation solutions, was founded in January 2021 by Hyundai Heavy Industries Group, the world's largest shipbuilder.

Challenges ahead

There are a few fundamentals we need to consider. Firstly, an autonomous system is a strategic (enterprise-level) game changer. The capabilities provided through autonomous systems are strategic and business-critical to the operators and owners. These capabilities exist at the core of the business, e.g. towage, sub-sea surveying and ferrying.

Secondly, an autonomous system is a complex system of systems operating in different market segments. Developing one complex system can be a technical challenge, developing a system of systems compounded by variation in different market segments is a whole other level of technical challenge. To allow for autonomous operations, we must consider the vessel's capabilities, the bi-directional connectivity solution and the remote operations centre as the system of interest. And all of this needs to cater to the strategic and operational needs of the business to provide value.

One of the key challenges when it comes to the adoption or a large-scale uptake of autonomous technology relates to legislation. The International Maritime Organisation (IMO) has communicated a mandatory Maritime Autonomous Surface Ships (MASS) code to be effective in 2032. The key question is, what do we do between now and 2032? And does the IMO have sole jurisdiction over an autonomous vessel in operation when the operator is located on land?

In the R&A domain, we see technology being in front of regulations. Possible challenges from future standardisation may force alterations or adaptations in the future—and as everyone working with products and solutions knows very well, changes in the concept phases are relatively cheap, whereas changes during the delivery or operational phase are much more costly. This is why programmes like the Horizon 2020 in the EU are vital to support the development of new innovative solutions from a concept on paper to real-life, full-scale solutions.

The review in [6] argues that MASS is a possible contributor to moving cargo from road to sea. The review also points out that the new technology MASS barrier to MASS uptake as it implies high investment risk and discourages potential investors. In [7], it is further pointed out that MASS will not take over the market overnight, and that the policy environment will define the adoption. They note that the market for MASS is limited and that a proper set of policy actions are needed. Accelerating a shift towards autonomous, green shipping can be achieved by prioritising autonomous ships in policy agendas and thus incentivising shipowners. Furthermore, shortcomings in the few available financial estimates are identified by [10].

More case studies quantifying the benefits of MASS are clearly needed, and new tools are required to support these case studies. Section 4.3 will discuss a tool that the AUTOSHIP project has developed for this purpose.

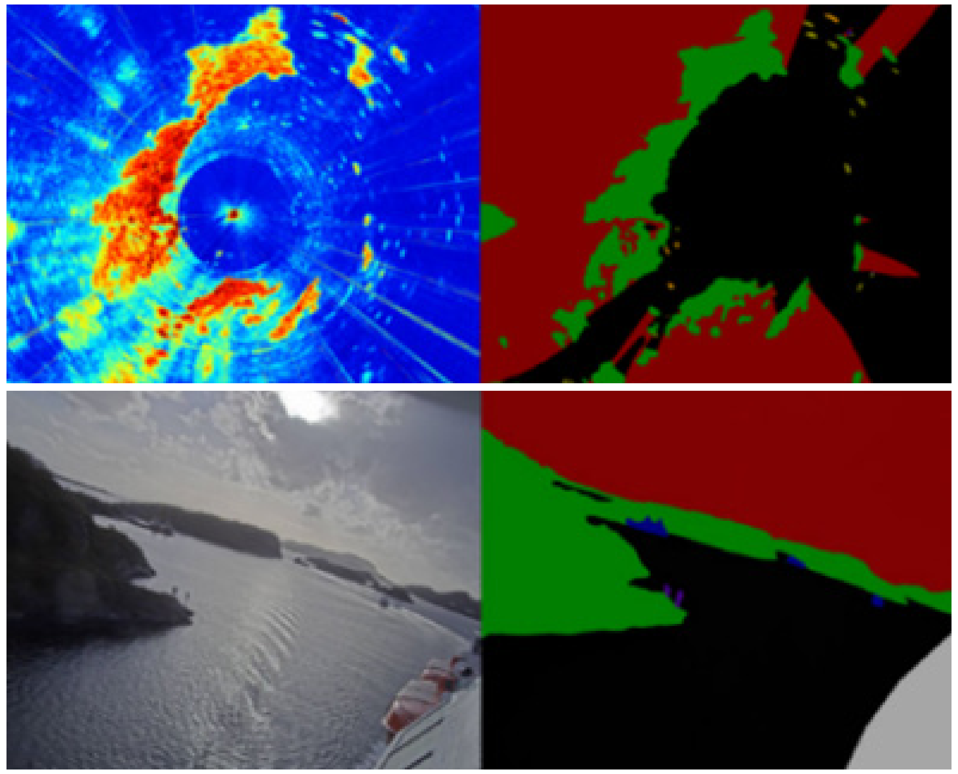


Figure 12: Camera and radar segmentation.

4. AUTOSHIP's role in overcoming autonomous shipping challenges

Technology development and demos

Situational Awareness

The Situational Awareness (SA) System aims to deliver a coherent solution for describing the environment the vessel is operating. The objective is to provide the operator with information necessary to enable safe navigation, whether the operator is a person or a machine. The SA system interfaces various sensors, including radar, cameras, GNSS receivers, motion sensors, gyro sensors, AIS and database information (Figure 12). The data is analysed and interpreted using advanced signal processing and neural networks. Large, diverse datasets of annotated sensor data are a key element of neural network development. The data is recorded from several installations and includes data from various locations and under different weather conditions.

Figure 13: Proximity view. (Top) Obstacle overlay. (Bottom) Aid lines overlay.

The main tasks for the SA system are:

- obstacle tracking (a multi-target multi-sensor tracker that provides information on surrounding objects such as other vessels and objects at sea, and aids navigation)
- obstacle classification (system classifies and determines the location, motion and size estimates of the tracked objects)
- mapping of the surroundings (determine the free space and obstructed areas and provide an updated map of the surroundings)
- capability monitoring (includes traditional system status and a module that at any time determines the system's ability to observe and classify the surroundings).

The objective is to provide current visibility, blind sectors and sensor performance of the system, which are affected by external factors such as weather conditions. The output of the SA system is shown in the navigation displays, such as the Electronic Chart Display and Information System (ECDIS), and as overlays in the AR video tool Proximity View, as shown in Figure 13. The picture on the left shows an example of how the overlay in video can provide information about the tracked obstacles. The right picture shows an example of how aid lines augmented on to the video may be used to guide the vessel through a narrow path.

Autonomous navigation

The **Autonomous Navigation System (ANS)** conducts the roles of the ship master and the ship navigator aboard the vessel. The overall tasks are to manage the vessel's current mission from port to port and navigate the remote-controlled or autonomous vessel in a safe, efficient and regulatory-compliant manner, handling undesired incidents in a way that reduces the overall risk.

ANS receives information on the surrounding obstacles and areas from the onboard object detection system (the SA system) and charts information from the ECDIS, using this data as input to assess and act upon collision risks. ANS also communicates with the Intelligent Machinery System to request changes to the vessel mode setup and get information on vessel capabilities. In addition, ANS allows the mission to be monitored remotely and in real time by an operator in an onshore remote operation centre. The link to shore also enables the operator to take control of the vessel.

Remote operation

The Remote Operation Centre (ROC) is a site remote from the vessel from which monitoring and control of some or all vessel functions can be executed. The ROC consists of the following subsystems:

- front-end, remote operator workstation (ROWS)
- back-end (main computers for ROC)
- connectivity and cybersecurity.

The ROWS is not designed to replicate the workstations onboard the vessel fully, nor is the ROC designed to replicate the vessel's bridge (see Figure 14).

There might be multiple navigation and manoeuvring workstations on the vessel's bridge, e.g. main conning position and bridge wing conning positions. This is mostly due to blind spots in visibility. In remote operation, the visual outlook is enabled by multiple onboard cameras that give proper visibility around the vessel. Video feeds, other situational awareness data, vessel systems data and regulated navigational systems like radar and ECDIS can be displayed on screens simultaneously. The data can also be augmented and layered to improve usability.

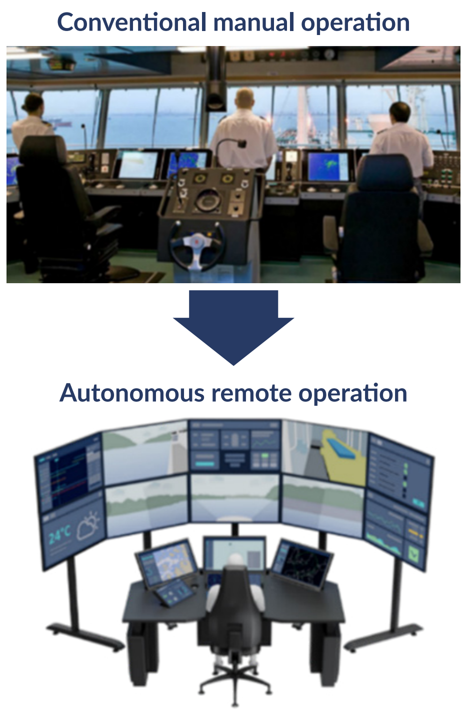


Figure 14: Vessel bridge operation vs. remote operation of an autonomous.

Demonstrations

The project aims to demonstrate the developed KET to TLR 7, which means system prototype demonstrations in a realistic operational environment. There will be two main demonstrations, one for each use case: Short-Sea Shipping and Inland Waterways.

The main objectives are to demonstrate:

- remote operations from the ROC in manoeuvring and sailing out of and into port
- autonomous sailing in 'open waters'
- auto docking at a selected port/ quay.

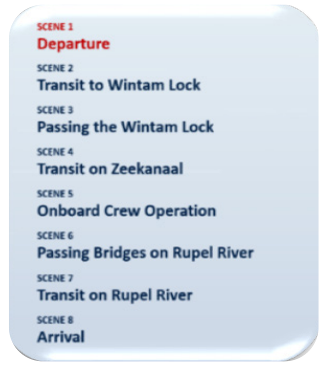
The demonstrations will involve the three main remote and autonomous technology pillars (Figure 15).

Figure 15: The three R&A technology pillars.

- Vessel Capability – includes SA, ANS and the Intelligent Machinery System.
- The Remote Operation Centre – the fourth developed KET. ROCs will be established in Ålesund, Norway and Wintam, Belgium.
- The Connectivity – the two-way connection between vessel and remote operations centre , the fifth developed KET, denoted here as the Connectivity and Cybersecurity System.

Brief descriptions of two use cases are provided in Table 1.

Table 1: Description of use cases of AUTOSHIP project.

Case	Short-Sea Shipping (SSS)	Inland Waterways (IWW)
Vessel	A fish feed carrier – MV Eidsvaag Pioner	Barge – Zulu 4
Photo		
Place	Skretting factory at Averøy on the northwest coast of Norway.	A test area of Rupel river, Schelde, Wintam and Zeekanaal south of Antwerp.
Upgrade	Installation of new relevant sensors, an upgrade to the latest versions of the vessel automation and control system and a planned upgrade of the vessel's conventional navigation system.	Adding equipment from Kongsberg Maritime AS that will perform situation awareness, autonomous navigation and manoeuvring.
Tasks	• Trained operators from Eidsvaag will carry out the remote and autonomous operations from the ROC. • Onboard ready crew handle operations and situations outside the autonomous capabilities of the vessel and systems.	• Evaluation of possible collision situations and calculation of collision avoidance routes • Monitoring of the operation of the vessel from the remote operation workstation using information from onboard systems and cameras • Communication between the Zulu barge and the Remote Operator Centre will be handled by a cyber-secure network using several different wireless carriers.
Demos	1. Sailing a normal fish feed distribution route at the northwest coast of Norway. 	Safety crew will be manning the Zulu barge, and the sailing will be monitored from a remote control centre in Wintam. 
	2. Transfer between Kristiansand in Norway and Hirtshals in Denmark 	

Research on safety

Several research and innovation initiatives have been pursued worldwide for the development of autonomous and unmanned ships. The introduction of the next generation of MASS is expected to bring substantial benefits by enhancing supply-chain resilience and operational efficiency, addressing the future deficit on seafarers, as well as reducing operational costs and greenhouse gas emissions. However, MASS, which can be classified in the category of complex socio-technical systems, are associated with unprecedented levels of systems complexity as well as multifaceted and unpredictable interactions between the involved subsystems, environment and humans. This may lead to new hazards and hazardous scenarios pertinent to the overall system safety, security and cybersecurity.

The wider adoption of MASS is limited by the gaps in the existing safety and regulatory frameworks, which do not provide guidelines and requirements for the design, testing and operation of autonomous ships. Additionally, challenges include the lack of acceptance criteria pertinent to the safety, security and cybersecurity for MASS, the lack of statistical data to perform the risk assessments, the need for customisation of the available safety methods, the gaps in the validation and verification of the required KETs and the overall system, as well as the need for testing strategies for the developed MASS.

The AUTOSHIP project addresses the preceding challenges by implementing several activities. First, a methodology for selecting appropriate risk matrix ratings, which are required to perform the risk assessment of autonomous and conventional ships at an early design stage, was developed. This methodology employs the individual and societal risk acceptance criteria to determine the risk matrix ratings for the groups of people exposed to risks (applied to the UC of IWW barge). The results demonstrated that the inclusion of societal risk resulted in more stringent risk matrix ratings compared to those employed in previous studies.

Second, an overview and ranking of the available traditional/classical safety methods, which are recommended in pertinent maritime standards. It demonstrated that classical hazard identification (HAZID) is a method widely adopted in the maritime industry for assessing risk at different design phases and is interconnected with risk acceptance criteria according to the IMO formal safety assessment (FSA) framework. However, HAZID may suffer from rigour and systematicity in the identification of hazards/scenarios. This was addressed by developing a novel hybrid, semi-structured method for hazardous scenario identification and ranking, which integrates the operational and functional hazard identification approaches, while considering the safety, security and cybersecurity hazards. The results revealed that the most critical hazards from the safety, security and cybersecurity perspectives pertain to the situation awareness, remote control and propulsion functions. Based on the derived results, design enhancements and high-level testing scenarios for the investigated autonomous ship are also proposed.

The AUTOSHIP project included a gap analysis using the aggregated results from the supply-chain mapping and involved phases/stages, the regulatory and insurance framework mapping and safety and risk assessments. Based on the KPIs qualitative ranking, several preliminary barriers were identified for the wider adoption of the scaled-up versions of the AUTOSHIP demonstrators, associated with the potential security and cybersecurity issues, limitations for the training of new personnel, limitations in the current infrastructure, lack of regulations allowing the wider operation of unmanned ships, and novel maintenance arrangements.

The recommendations to mitigate the identified gaps in the legal frameworks are: to give autonomous ships wide acceptability and freedom of movement in different flag and port and coastal states' jurisdiction; and bilateral agreements among interested parties, which could be a solution at the initial stage of MASS operation (but would take a long time). There will not be an issue with a ship's manning requirement to enjoy the right of innocent passage as autonomous ships are considered ships and are not engaged in the activities mentioned in Article 19 (2) of UNCLOS.

The AUTOSHIP project focuses on developing and proposing a safety assurance framework to support the design of safe, secure and cyber-secure MASS. This framework consists of three phases associated with the three major design phases: preliminary design, detailed design and verification and validation activities. The framework is aligned with the existing guidance for assurance of MASS and novel technology in the maritime industry. The main weaknesses of existing guidance and standards can be attributed to several factors: lack of detailed testing procedures for the KET required to make MASS operatable; lack of standardised approaches for guiding the design and implementing the preliminary risk assessment; and the need to 'marinise' pertinent guidelines that exist in other industries to make them applicable to MASS and ships in general. The developed framework and novel methods can be applied in conjunction with other established methods, guidelines and standards. Requirements about qualification, education, training, certification and watchkeeping schemes and watchkeeping principles for remote operators are referred to the D7.2 (Training framework for the crew, operator and designer) of the AUTOSHIP project.

Logistics perspective and decision support

Logistics perspective and Decision Support System

Autonomous shipping is attractive as it will increase the competitiveness of waterborne transportation. But is this always true? To advance the state of the art for autonomous ship business cases, the following central questions must be answered:

- How is transportation cost influenced by autonomy?
- How will autonomy impact emissions, and what mechanism is most important (increased cargo capacity, removal of equipment related to the crew, reduced wind resistance, reduced light weight, etc.)?
- How do these factors relate to the market segment?
- In which applications will autonomy give the most benefits, i.e. which applications should be prioritised for initial development, investment and public funding?

To fill this knowledge gap, we need more studies of MASS application cases. And to make such case studies simpler and comparable, the AUTOSHIP project has developed a toolkit called Decision Support System (DSS) for autonomous ship investments.

Decision Support System for autonomous ship investments: overview and workflow

The toolkit consists of two applications that work on the same project and share data (Figure 16). One that can be used to design and analyse the logistic system is called the logistics analysis tool (LA tool), and one that can be used to estimate transportation costs and emissions is called the MASS analysis tool (MA tool).

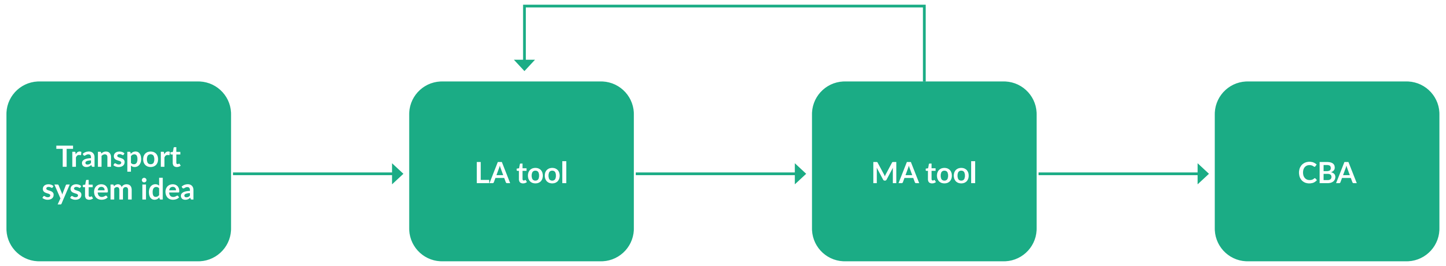


Figure 16: Decision support system workflow.

The toolkit can be used to transform a transport system idea into a high-level logistic system design by modelling it and to estimate the transportation cost and emissions for transporting cargo by the transport system concept. The first step is to model the logistic system and run simulations to estimate logistical KPIs. Parameters such as ship size, sailing schedule, cargo handling equipment and route are varied until a satisfactory cargo flow fulfilling the transportation need is achieved.

The next step is to model costs and ships (energy models) and to estimate transportation costs and emissions for each sub-part of the transportation network, and the network as a whole. Both tools estimate KPIs and the user can adjust the design in both tools. This means that changes done in one tool may have an impact on the results of the other, and that it may be necessary to iterate a few times over the two tools.

When a concept design with satisfying logistical, cost and emission performance is achieved, the estimated KPIs can be used in a cost-benefit analysis to determine if it is worth investing more time and money into further developing the transportation and ship system concept.

The LA tool

The logistic system model in the LA tool consists of locations for production, consumption and transferral of cargo, the ships transporting the cargo between the locations, the cargo handling equipment on ships and locations, capacities and handling rates, cargo production models and ship schedules. Details on the modelling method are given in [12]. This model can be used in agent-based simulations [13] to estimate logistical KPIs such as cargo lead time between any location in the network, shipment frequency, ship and location storage capacity utilisation, and ship schedule keeping. These simulations are quick, and it is easy to iterate over different versions of the concept idea.

Example – To illustrate how the LA tool is used, we include the following simplified

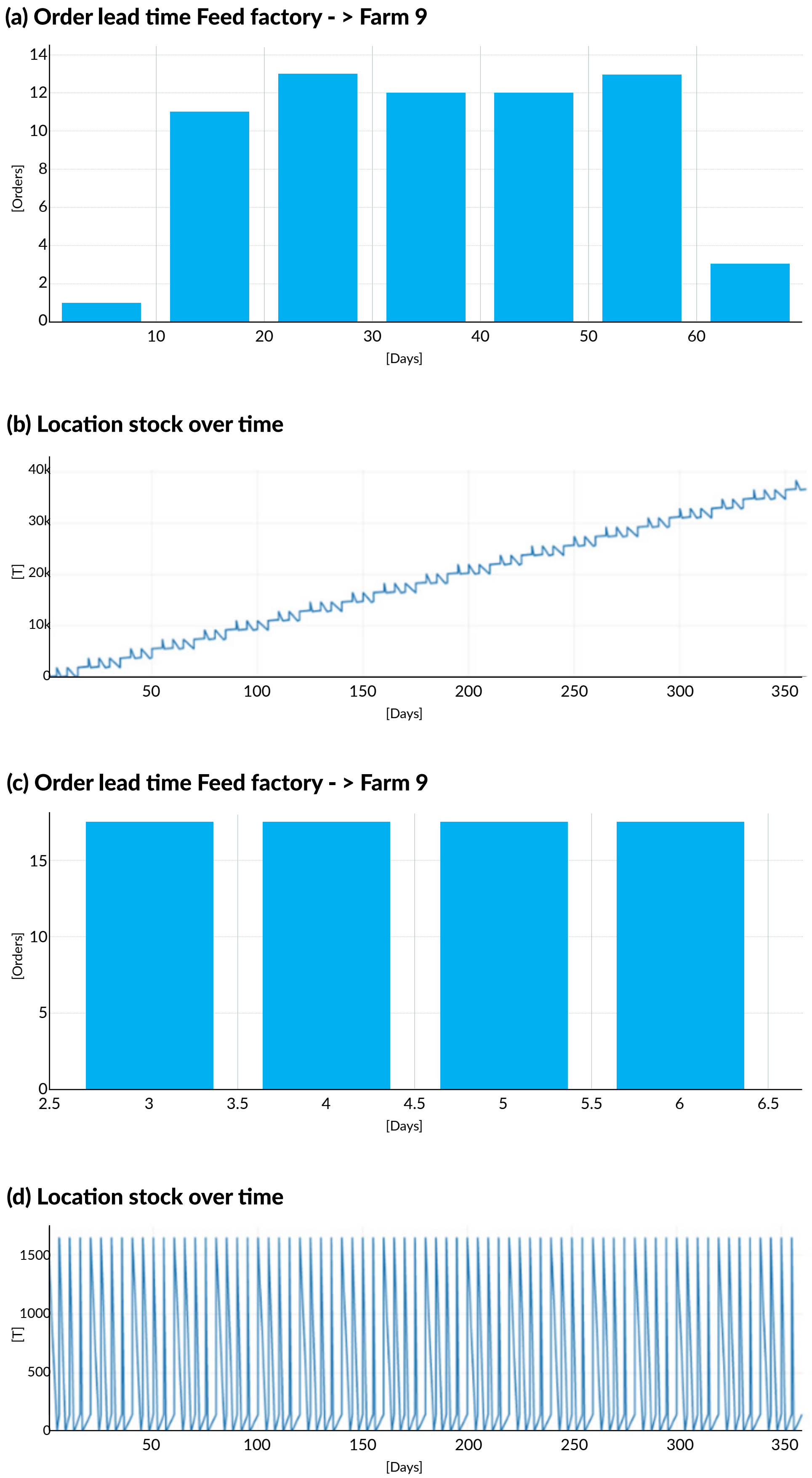


Figure 17: SINTEF DSS toolkit, example results: lead time (a) and location stock (b), lead time (c) and location stock (d).

example where some of the estimated KPIs are included. The example is for a rather simple logistic system (however, it is also possible to analyse more complex logistic systems where several ships operate on different routes connected through terminals):

- One location produces cargo organised in orders that are to be delivered to different locations (11).
- One ship loads all orders and delivers to the defined locations consuming the orders along one route.
- The ship sails once a week at 14 knots average speed.
- Orders are produced every fifth day.
- Simulation time is 365 days.

The results show that the ship keeps its schedule well but spends approximately 80 hours a week waiting for the next voyage. Looking at the lead time, e.g. from producer to location nine seen in Figure 17 (a), we see that orders are delivered up to 60 days after they are ready to be loaded and that cargo is building up at the producer. Since the ship is waiting approximately 80 hours a week for the next voyage, we can change the schedule such that the ship sails every fourth day. As a result, the lead time is between three and six days, and location stock is stable as the orders are transported at the same rate that they are produced. When obtaining a stable logistic system with satisfying logistical KPIs, one can move on to estimating cost and emissions in the MA tool.

NOTE: KPIs can be viewed per location, ship and for each to-from location.

The MA tool

As we will discuss in the section 'LA tool generated MA tool simulations', a set of typical shipments can be generated by the LA tool. A shipment is a set of orders which are to be loaded at a producer and delivered in parts, defined by the orders to consumer locations. Statistical weather can be configured for the route, either for the whole or for as many sections of the route as wanted. Each section can have one or more weather profiles, weighted by how much time each profile is valid. One simulation and estimation will be run for

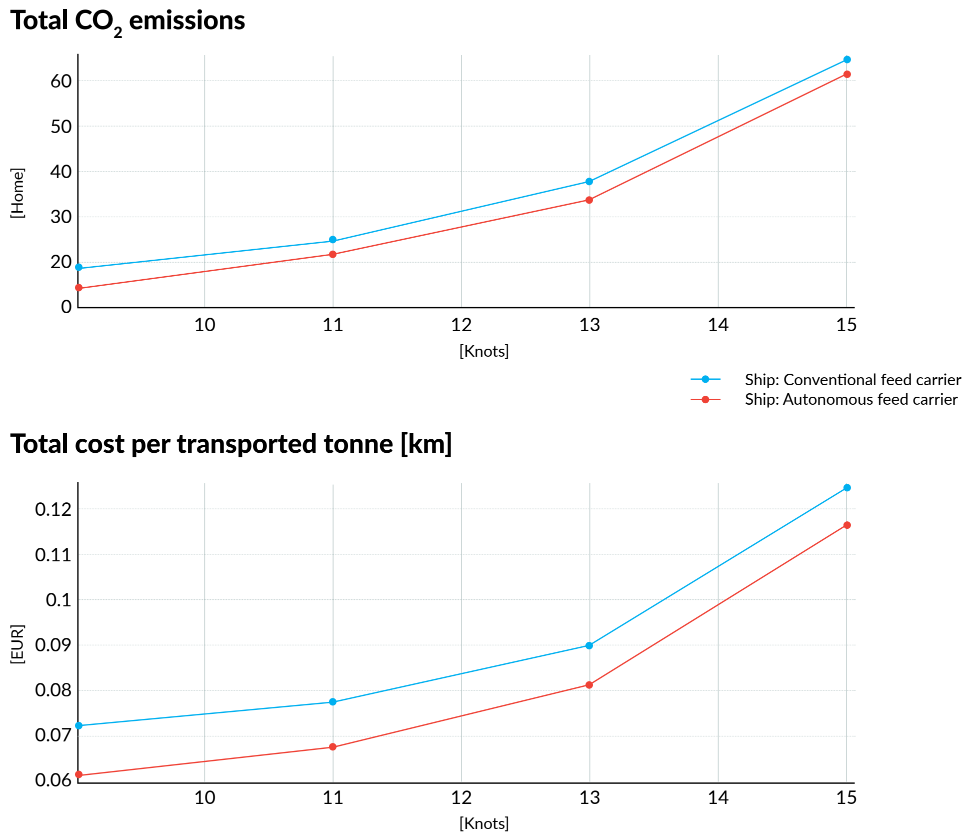


Figure 18: SINTEF DSS toolkit MA tool, CO_2 emission above, transport cost below.

each profile and aggregated into average energy consumption, cost and emission estimations, based on the same models as the LA tool. Moreover, the ship and location models are extended, and RCC, port cost and weather models are added.

Example – To continue the example in the MA tool, we insert some approximated data to run MA tool estimations. The ship model is extended with a hydrodynamic model of a bulk carrier, estimated construction cost from a regression model [14], machinery model for emission estimation, cargo handling, hotel and auxiliary energy, operational costs, interest rate and years of depreciation. RCC costs are either estimated by using the built-in estimation model or configured as a lump sum estimate. Locations are configured similarly to the LA tool, but each location is connected to a port cost model. The port cost model is a set of tables mapping transferred cargo, ship size and duration of stay, to costs.

While the LA tool simulates order production and forms shipments based on the transportation need at locations producing orders, the MA tool requires that shipments are configured explicitly. This is because the MA tool does not simulate the cargo flow over time. Instead, it simulates one or more typical voyages and estimates average costs and emissions.

Results

The example results are for the comparison of an autonomous and conventional version of the same hull, where the autonomous version has no superstructure and increased cargo capacity, but both ships have the same hull shape and dimensions. Shipments correspond to typical shipments from the LA tool example simulations, and the MA tool simulations are run for an average sailing speed of 9 to 15 knots.

The tool can display several KPIs, details are given in [14] , and some examples are CO_2 emissions and transportation cost, see Figure 18.

NOTE: KPIs can be viewed per ship and for each to-from location.

LA tool generated MA tool simulations

The toolkit enables a series of MA tool simulations to be generated when the user wishes to estimate the transport system's costs and emissions. Based on the results of the LA tool simulations, a clustering algorithm is run to estimate the typical shipments carried between each location of the logistic system. The algorithm outputs a set of shipments for each sub-route of the logistic system, where one sub-route is the set of locations visited by one ship and the waypoints that connect the locations. The algorithm also estimates a weight for each shipment, where the weight represents the percentage of time that the given shipment is transported, and where the sum of the weights for one ship and its route is one. One MA tool simulation is generated for each ship, route, and shipment combination. Results give average emission and transportation costs for each ship-route combination.

Comparison to truck transportation and estimation of the external cost impact

The tool also offers the option of estimating truck transportation cost and estimated external cost impact by replacing the truck transportation with the waterborne logistic system concept. The LA tool generates all the transportation legs the trucks must perform, that is, all the producer-consumer connections. The user inputs average driving speed, distance and cost parameters. For external costs, KPI-to-cost conversion parameters are taken from [1], but can be overridden by the user.

Running this tool for our example, we find that the ship has a higher transportation cost to the first five locations and a lower transportation cost to the last six locations, compared to the trucks. We also find that the impact on external costs presents society with the ability to save approximately €1.3 m if the transport was moved from road to sea.

While the estimates are uncertain, all input parameters can be varied to perform a sensitivity analysis. The estimated KPIs can be used in a cost-benefit analysis to support a decision as to whether to move forward with the concept or not.

Conclusions

The application of new technologies for digitalisation and automation may rapidly change the way maritime transport works and operates. Development towards fully or partly autonomous ships will pose both opportunities and challenges for the sector, potentially increasing safety, security and sustainability, while needing to tackle gaps in existing legal frameworks and finding the right lock-pick to step into the traditional operations in the maritime business.

To address these challenges and gaps, AUTOSHIP undertakes several activities, such as validating R&A technologies onboard and in their onshore control centres, based on requirements and added value for the shipping industry in the SSS and IWW sectors. While the demonstrators will likely constitute a novel platform to show off to other investors, additional research has led to developing a novel security and safety approach as well as design and decision support suites to model the entire value chain. The shipowners' business cases have also been studied to measure the profitability of autonomous system investment and competitiveness with respect to trucks. A proposal to IMO for amending and improving the regulation will conclude the project's outreach on the regulatory side.

The proposed risk assessment approach can be used for the analysis of other MASS in their preliminary design phase, as it facilitates the mapping of the hazardous scenarios and provides recommendations for the design's safety/security/cybersecurity assurance. However, further studies are required to ensure the results' verification and reduce uncertainty in the ranking and hazard identification. For instance, a dedicated cyber-risk assessment is required according to the classification societies' guidelines to address the cyber risks. In addition, a separate HAZID session addressing all the causal factors is required for the verification of the final design.

The determination of the current safety level for a fleet of conventional ships, as well as the adaptation of the proposed methodology for application in other industries and investigations for other ship types, need to be studied.

Future studies are expected to investigate the implementation of a roadmap and its timelines, while following the developments of technologies for realising the next-generation autonomous ships and their related infrastructure.

Adobe Stock © enanuchit

Bibliography

[1] H. Van Essen, L. Van Wijngaarden, A. Schroten, D. Sutter, C. Bieler, S. Maffi, M. Brambilla, D. Fiorello, F. Ferni, R. Parolin and K. El Beyrouty, *Handbook on the external costs of transport*, European Commission, 2019.

[2] T. T. Nguyen, H. Ghaderi, L. D. Caesar and S. Cahoon, "Current Challenges in the Recruitment and Retention of Seafarers: An Industry Perspective from Vietnam," *The Asian Journal of Shipping and Logistics*, pp. 217–242, 2014.

[3] T. Suzuki, "Challenge of Technology Development through MEGURI 2040," *ClassNK Technical Journal*, no. 3, 2021.

[4] J. de Vos, R. G. Hekkenberg, A. Osiris and B. Valdez, "The Impact of Autonomous Ships on Safety at Sea – A Statistical Analysis," *Reliability Engineering and System Safety*, no. 210, 2021.

[5] A. A. Allal, K. Mansouri, M. Youssfi and M. Qbadou, "Toward energy saving and environmental protection by implementation of autonomous ship.," in *19th IEEE Mediterranean Eletrotechnical Conference, MELECON 2018* - Proceedings, 17, Marrakech, 2018.

[6] G. Theotokatos, J.L.D. Dantas, G. Polychronidi, G. Rentifi, M. Molica Colella, "Autonomous shipping — an analysis of the maritime stakeholder perspectives", *WMU Journal of Maritime Affairs*, ISSN 1654-1642, 2022.

[7] M. Molica Colella, T. Scandale, A. Invito, I. Panza, J. Bolther, "AUTOSHIP deliverable D9.6: Stakeholder Analysis Report, AUTOSHIP H2020" 2021.

[8] Z. Munim, "Autonomous ships: A review, innovative applications and future maritime business models," *Supply Chain Forum*, vol. 20, no. 4, pp. 266–279, 2019.

[9] T. Fonseca, K. Lagdami and J. Schröder-Hinrichs, "Assessing innovation in transport: An application of the Technology Adoption (TechAdo) model to Maritime Autonomous Surface Ships (MASS)," *Transport Policy*, vol. 114, pp. 182–195, 2021.

[10] Y. Gu, J. Goez, M. Guajardo and S. Wallace, "Autonomous vessels: state of the art and potential opportunities in logistics," *International Transactions in Operational Research*, vol. 28, no. 4, pp. 1706–1739, 2020.

[11] C. Bălan, "The disruptive impact of future advanced ICTs on maritime transport: A systematic review," *Supply Chain Management: An International Journal*, vol. 25, no. 2, pp. 157–175, 2018.

[12] E. Ziajka-Poznańska and J. Montewka, "Costs and benefits of autonomous shipping—a literature review," *Applied Sciences (Switzerland)*, vol. 11, no. 10, 2021.

[13] H. Ghaderi, "Autonomous technologies in short sea shipping: trends, feasibility and implications," *Transport Reviews*, vol. 39, no. 1, pp. 152–173, 2019.

[14] H. Nordahl, Y. Kisialiou, L.A.L. Wennersberg, "AUTOSHIP Deliverable D7.5: Complete supply chain and logistics model, AUTOSHIP H2020" 2021.

[15] J.S. Dæhlen, E. Sandvik, A.I. Rialland, B. Lagemann, "A Method for Evaluating Ship Concepts in Realistic Operational Scenarios using Agent-based Discrete-Event Simulation," in *20th International Conference on Computer and IT Applications in the Maritime Industries (COMPI21)*, 2021.

[16] H. Nordahl, N. Dag Atle, E. Lindstad, "Autonomous ship concept evaluation–Quantification of competitiveness and societal impact," *Journal of Physics: Conference Series*, vol. 2311, no. 1. IOP Publishing, 2022.

[17] C. Bălan, "The disruptive impact of future advanced ICTs on maritime transport: A systematic review," *Supply Chain Management: An International Journal*, vol. 25, no. 2, pp. 157–175, 2018.

[18] C. Chae, M. Kim and H. Kim, "A Study on Identification of Development Status of MASS technologies and Directions of improvements," *Applied Science* (Switzerland), vol. 10, no. 13, 2020.

[19] J. Wang, Y. Xiao, T. Li and C.L.P. Chen, "A Survey of Technologies for Unmanned Merchant Ships," *IEEE Access*, vol. 8, pp. 224461–224486, 2020.

[20] H. Nordahl, Y. Kisialiou, L.A.L. Wennersberg, "AUTOSHIP Deliverable D7.5: Complete supply chain and logistics model, AUTOSHIP H2020," 2021.

Authors

Marco Molica Colella, CiaoTech - PNO Group, Managing Consultant R&D Advisory Services. **Email** **LinkedIn**
Anastasiya Azarko, CiaoTech - PNO Group, Junior Innovation Consultant. **Email** **LinkedIn**
Ørnulf Jan Rødseth, SINTEF Ocean AS, Senior Research Scientist. **Email** **LinkedIn**
Håvard Nordahl, SINTEF Ocean AS, Senior Research Scientist. **Email** **LinkedIn**
Gerasimos Theotokatosthe, Professor of University of Strathclyde. **Email** **LinkedIn**
Thoralf Ruud, Kongsberg Maritime AS, R&T Programme Manager. **Email** **LinkedIn**
Vidar Helgas, Kongsberg Maritime AS, Senior Engineer. **Email** **LinkedIn**