WP4 Smart Shipping implications in Logistics Chains

Autonomous Shipping technology: Implications in Logistics chains, and a Case for Adoption in Zeeland

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Autonomous Shipping technology: Implications in Logistics chains, and a Case for Adoption in Zeeland

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Abstract

Autonomous shipping appears as a promising solution to reducing operational costs and improving logistics on inland waterways. The following research focuses on inland shipping in Zeeland, Netherlands to examine how autonomous shipping can impact logistics chains and be adopted by using inland shipping services in North Sea Port. The Dutch inland shipping industry is facing a sharp decline in skippers as it is no longer an attractive role therefore, an investigation is carried out using industry-wide literature to compare with data and contrast with stakeholders in the region to find what the main drivers of adoption are, which industries will be the most likely to adopt autonomous shipping technologies first and to which extent will the required skills be transferred to an onshore control center. The research is broken down into technical feasibility, economic benefit, and human participation finishing with recommendations and a proposed adoption model from a Zeeland perspective.

Introduction

In Zeeland, Netherlands, there is a high activity of inland vessel operations due to a cluster of inland and short sea terminals in Vlissingen, Terneuzen, and Gent referred to as North Sea Port. Many goods are transhipped from sea-going vessels or produced locally and shipped inland but neither of these routes involve autonomous shipping. Autonomous shipping brings benefits such as reduced operational costs, improved efficiency, and increased safety (Rødseth, 2018; Tsvetkova & Hellström, 2022). This is achieved by reducing the crew needed onboard each vessel through skipper automation. A large portion of mature skippers are pensioning at the end of this decade. In addition, the EU is promoting the use of waterborne transport for environmental benefits, but it is still unclear who is going to do this job if there is a shortage of skippers. Lead times are often long in inland shipping due to route planning, the nature of the waterways, and the resting of the crew. Autonomous shipping allows the possibility of 24/7 operations with increased capacities and sustainable sailing so is, therefore, a possible solution.

However, this technology has not yet reached Zeeland as it is not clear what changes need to be made by relevant stakeholders to adopt this technology. Stakeholders such as North Sea Port, government bodies, and industries in Zeeland seem to be still not up-to-date in terms of the infrastructures required to accommodate the higher volumes of goods brought by improved logistics (Alias & Felde, 2022).

Therefore, the relevant questions that must be asked are: Which type of inland shipping markets will want to adopt autonomous shipping first? Based on what? And what is the added benefit of doing so?

Scope of the Research

The focus of this research will be on how autonomous shipping technologies can be applied to the logistics domain and adopted in Zeeland, more specifically in the North Sea Port terminals. Although North Sea Port includes Ghent, a focus will only be on the Zeeland-based ports of Vlissingen and Terneuzen due to the difference in legislation between the Netherlands and Belgium, but inspiration from current smart shipping operations in Belgium will be considered.

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This study is limited to European inland shipping with technological inspiration taken from the short sea shipping sector and applied to inland shipping. Finding the current state of the art in technology is one of the aims of this research which will involve investigating multiple industry-wide publications to test in interviews with experts so that adoption gaps are identified and the most up-to-date information is gathered.

For autonomous shipping to be adopted in practice it must be profitable. Therefore, this research aims at finding the costs and benefits that this concept brings. Many challenges that face logistics will be discovered such as the impact on operational costs, safety, lead time, and environment.

The level of human involvement when autonomous shipping passes through multiple levels of adoption is focused on the change of skills that will be required to operate autonomous inland vessels. The three inland shipping markets in focus within this research are liquid bulk, dry bulk, and containers due to being the largest three barging transportation markets in Zeeland (see Figure 1). Other segments are present in Zeeland such as general cargo but for the sake of simplicity and clarity, only three of these markets will be in scope.

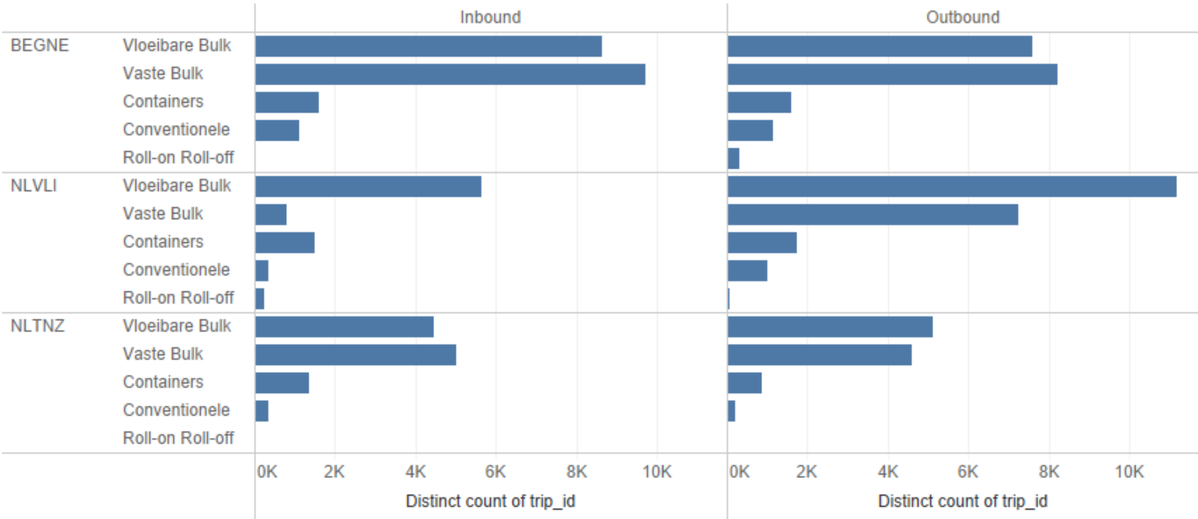

Figure 1: Count of trips from 2021-2023 using North Sea Port. Source: (North Sea Port, 2023)

1 Importance of Research

There are currently many research projects being carried out by multiple institutions concerning autonomous shipping and a clear consensus of where the current state of the art stands has not been created. It is not clear what autonomous shipping can do now and in the future, so exploration must take place using relevant literature and combining information from other research with primary data from companies so that an accurate application to maritime logistics in the Zeeland perspective can be achieved. It is also not clear who will want to adopt these technologies first and based on what drivers. Adoption is driven by addressing the challenges and concerns that face inland autonomous shipping. Drivers of the problem include high operation costs, safety, legislation, operational inefficiencies, environmental impact, and labor shortages. Each of these problem drivers is addressed in this research and proved to show that this technology is the ideal solution.

1.1 Who is at stake?

Multiple stakeholders are involved in the focus of this research. These are as follows:

- **Barge Owners/Operators:** Owners and operators of inland vessels are often the same person or in a family. They are responsible for the management and maintenance of the vessels alongside looking after the rest of the crew, organizing paperwork, ensuring safety requirements are met, and most importantly carrying out the transportation of goods from A to B.

- **Terminals:** Terminals are responsible for the transshipment of goods through multimodal operations. They plan, handle, load, and unload various cargo types onto the vessels as well as refueling.
- **Port Authorities:** Port authorities, in this case, North Sea Port, oversee the operations of each terminal located in their port area. They are in control of the infrastructures for calling and departing vessels in terms of connectivity and navigation, ensuring legislation and regulations are met along with ensuring vessels are unloaded and loaded safely.
- **Dutch Government Bodies:** Local governments establish policies, regulations, and legislation to be followed within the country and regions. They monitor the environmental impact of the country as a whole and set targets and goals to reduce the impact of emissions.
- **EU Commission:** An executive politically independent part of the European Union and the European Council. They draw up proposals for each of the 27 member states and implement the decisions of the EU.
- **Technology Developers:** Those who design, process, pilot, and test autonomous shipping technologies and present them to relevant stakeholders for investment.

To the best of our knowledge, no research has been conducted about the opinions and perceptions of stakeholders in Zeeland regarding autonomous shipping, to which level they are interested in adopting, and which aspects are not welcomed in their operations. Then, the originality of this study lies in the fact that it focus specifically on Zeeland stakeholders.

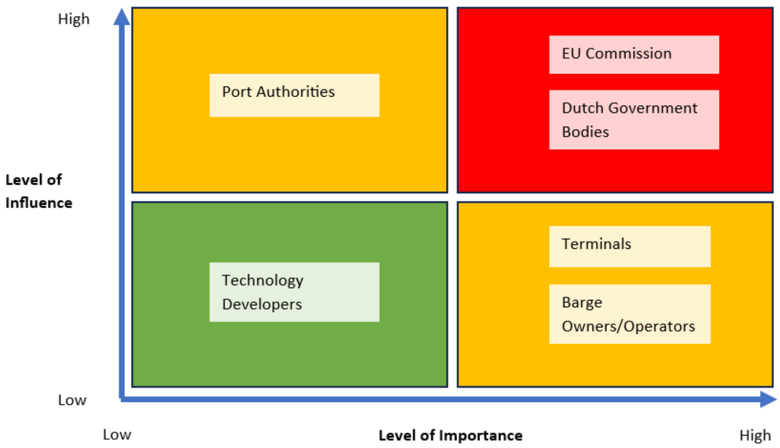

Figure 2: Stakeholder Analysis for Inland Autonomous Shipping Adoption in Zeeland. Source: Own authors

1.2 Why is it important?

In a holistic view, the mentioned problems all source at the need for clarity of how autonomous shipping will be introduced to Zeeland. For technology adoption to take place each aspect of it must be transparent to all relevant users so that a maximum value can be reached by each stakeholder. Within the maritime industry, the labor shortage is high. Fewer people are choosing careers as skippers (Pauwelyn & Turf, 2023). A large portion of mature skippers are pensioning at the end of this decade and the Dutch labor market for skippers, sailors, and other sailing personnel will be 25% smaller in 2030 compared to 2021 (SMASH! 2023). In addition, the EU is promoting the use of waterborne transport (as is cleaner) but, who is going to do this job if there is a shortage of skippers? Autonomous shipping can be a solution to that. It is also worth considering that the majority of shipping accidents are human-generated (Maternová et al., 2022) therefore it is thought that this technology will bring a safer navigation environment.

All relevant literature on smart shipping will be explored, which are ships operated by machinery and systems making their own decisions (Cross & Meadow, 2017). Exploring literature will help get up to speed with the current state of the art in technology from a vast range of sources. Autonomous shipping can reduce human error, decrease crewing costs, and increase safety, and fuel efficiency (Network, 2020). From a cost perspective, it is important to identify where in the profit and loss sheet these cost savings occur and to what extent. The variation of routes, vessel types, and industries make it difficult to pinpoint exactly how much is saved but it is figured that crew costs can account for around 45% of all operating costs (Kretschmann et al., 2017). Reduction in crew levels will create an interruption to the roles and requirements of the inland shipping industry. When smart shipping is adopted through its various stages it is expected that manning levels will reduce as a result (Ringbom, 2019) therefore, preparations for these new ways of working are to be made.

1.3 Problem Statement

It is expected that autonomous shipping technology will be developed and made available step by step in the coming years. To realize its added value in the logistics chains in Zeeland, several adjustments are needed. These adjustments are in the operational management of shipping, terminals, and the infrastructure of ports. In theory, it requires less crew on board, but it is also known that to ensure safety and reliable sailing in certain situations, a skipper on the bridge is necessary. This makes it unclear how autonomy will be adopted in Zeeland. This strongly depends on the level of technology adoption in terminals, infrastructure, and on the vessel itself. The possibilities and impacts of autonomous shipping are still unclear to the relevant stakeholders. The questions for Zeeland industries are: Why should terminals and shippers adopt this technology? What is needed from terminals and government bodies to allow the transition to autonomous shipping? And, how will autonomy impact the human role of inland shipping?

Consequently, the following research questions are proposed:

- What are the drivers of the adoption of inland autonomous shipping by logistics chains in North Sea Port terminals in Zeeland?
- What market segments are the ones first expected to adopt autonomous shipping in Zeeland logistics chains?
- What is the roadmap of actions to enable autonomous shipping uptake in logistics chains in Zeeland?

The proceeding sections of this paper will include a literature review to get up-to-date with the relevant technologies, benefits from autonomous shipping and how humans are impacted to answer the theoretical questions. The research methodology will then be explained followed by primary data gathering which will all be used to answer the main and empirical research questions in the empirical findings section and conclusion. Lastly, some recommendations, discussions will be given followed by additional information for the reader in the appendix.

2 Literature Review

In this section, the relevant literature is explored to answer the theoretical questions. Due to a scattered number of studies available surrounding autonomous shipping, the review is scoped to involve literature mainly applicable to inland shipping with worldwide inspiration taken from deep and short sea shipping where it is relevant. The objective of this examination is to identify all relevant known literature on autonomous shipping to use as a basis for building a framework that also includes insights from relevant users to explore how this technology can impact logistics and be adopted by various stakeholders.

2.1 Smart Shipping adoption literature

Regarding the theoretical foundation on the topic of the adoption of new technology, the Diffusion of Innovations theory, presented by Rogers (1995), is the most widely employed theoretical framework in research related to the adoption of technological innovations (Park et al., 2022). Rogers (1995) is credited with introducing the terms *adoption* and *diffusion* and proposed a definition of innovation that is presently among the most widely embraced (van Oorschot et al., 2018; Wiśnicki et al., 2021). In his description, innovation is "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (Rogers, 2003). Rogers (2003) also developed the conceptual framework for factors influencing the diffusion of innovations and outlined the attributes that impact the decisions of early adopters.

He proposed that several characteristics of an innovation that have been found to affect the rate of adoption as mentioned by Wiśnicki et al., 2021:

- Relative advantage – the degree to which an innovation appears to be better than the solution it supersedes or a competing product;
- Compatibility – indicates whether an innovation appears to be consistent with the existing values, experience and needs of prospective adopters;
- Complexity – the degree to which an innovation appears to be difficult to understand and use;
- Trialability – to what extent an innovation can be introduced gradually and for trial;
- Observability – to what extent the results of an innovation are visible to others.

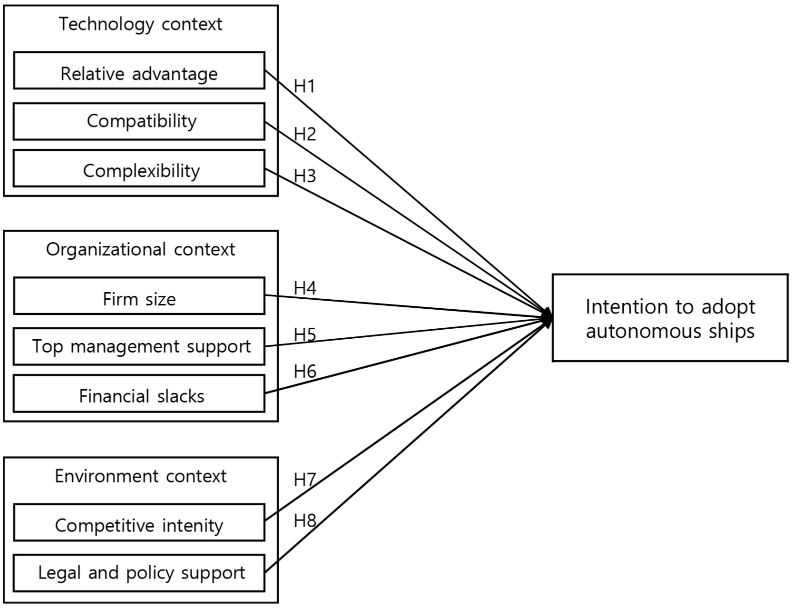

Figure 3: A conceptual model for the intention to adopt autonomous ships. Source: Park et al., 2022

The theory of the Diffusion of Innovations (DOI) can be complemented by other theories. For example, the Technology-Organisation-Environment (TOE) framework proposed by Tornatzky and Fleischer (1990). This model delineates three dimensions within an organization's context that exert influence over its adoption and execution of technological innovation: technological, organizational, and environmental factors. The technological dimension describes the technologies relevant to the company (internal and external to the enterprise). The organizational dimension relates to the organizational characteristics such as its scope, size, management structure, and degree of centralization, among others. The environmental dimension refers to the environment in which a firm conducts its business – the industry, competitors, and regulatory aspects (Oliveira & Martins, 2011).

Drawing from DOI and TOE frameworks, Park et al. (2022) proposed an adoption model for autonomous ships (Figure 3). This model was empirically tested with Korean maritime and inland shipping stakeholders, and it was found that Top Management Support (H5), Financial Slacks (H6), and Competitive intensity (H7) have a significant effect on the intention to adopt smart ships.

A model of technology adoption in the context of transportation technologies is proposed by Fonseca et al. (2021), and is referred to as the "TechAdo" model. Authors argue that a multi-factor model is needed for assessing emerging technological innovations in transportation. Identifying the economic benefits, technical feasibility, and human capital can help bring structure to a complex analysis that involves many sources (see Figure 4). Fonseca et al. (2021) also highlights that factors in the enabling environment such as governance, social acceptance, and regulation along with economic benefits, technical feasibility, and human capital need to be thoughtfully considered in future research and policy.

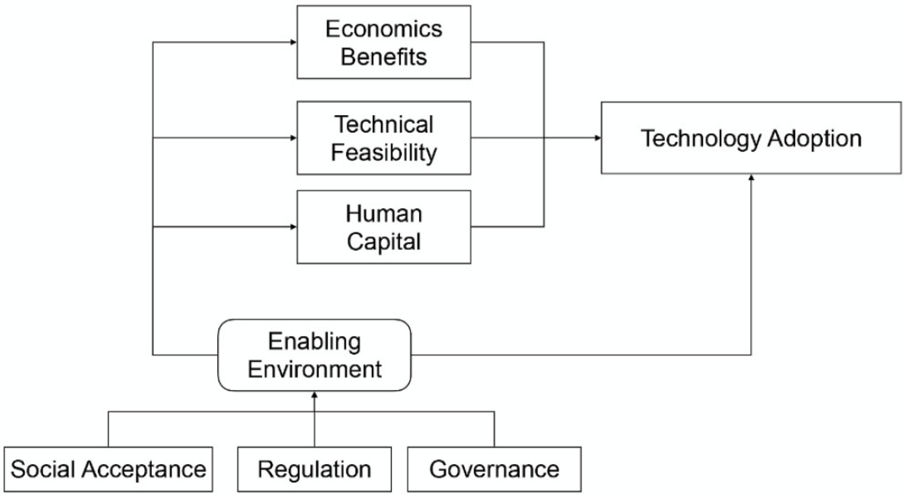

Figure 4: TechAdo model for assessing emerging technologies in transport. Source: Fonseca et al., 2021

Finally, Nordahl et al. (2023) attempted to materialize a roadmap for the adoption of autonomous shipping. To achieve this, they investigated the constraining factors for the societal adoption of this technology by using the PESTLE method. The reasoning is that if the barriers of adoption (i.e. constraining factors) are removed or addressed, then this will result in society adopting smart shipping. Figure 5 displays these factors and how they need to be addressed to trigger adoption in the long term.

When looking at these adoption models found in the literature, one can see some common factors. As Nordahl et al. (2023) put it: “to make an investment decision in an autonomous ship, it must be technically possible to realize the ship, it must be legal to operate it, necessary infrastructure and support services must be available at an affordable cost, the price must be sufficiently low to make the investment profitable, and there must be a viable business model for operating the ship and for providing the required services to the autonomous ship”.

Throughout this report, a focus will be put on the economic benefits, technical feasibility, and human capital (Fonseca et al., 2021) so that each factor can be investigated in depth and compared with the relevant stakeholders’ information through interviews. Each of these three criteria is the box that needs to be ticked for autonomous shipping adoption to take place and form part of the structure of the theoretical questions. An enabling environment (as a subsystem shown in Figure 4) as a factor will be kept out of scope in this literature review as a business case must be made first before government bodies can consider accepting. The benefits of autonomous shipping are also investigated so that a business case can be made for those who choose to adopt this technology.

2.2 Which autonomous shipping technologies should be applied to maritime logistics?

To identify the shipping technologies that should be applied to maritime logistics, the relevant technologies are divided into three pockets based on their applications: communication, navigation, and propulsion. Throughout exploring literature, each technology is grouped into its purpose and function leading to the creation of these three pockets.

2.2.1 Communication

Satellites Data transfer plays a key role when it comes to the operation of autonomous ships. Satellite communication is one of the fastest-improving technologies so far (Kooij et al., 2018) and it can account for inland and deep-sea shipping making its principle valid. Data transfer for inland vessels must be fast

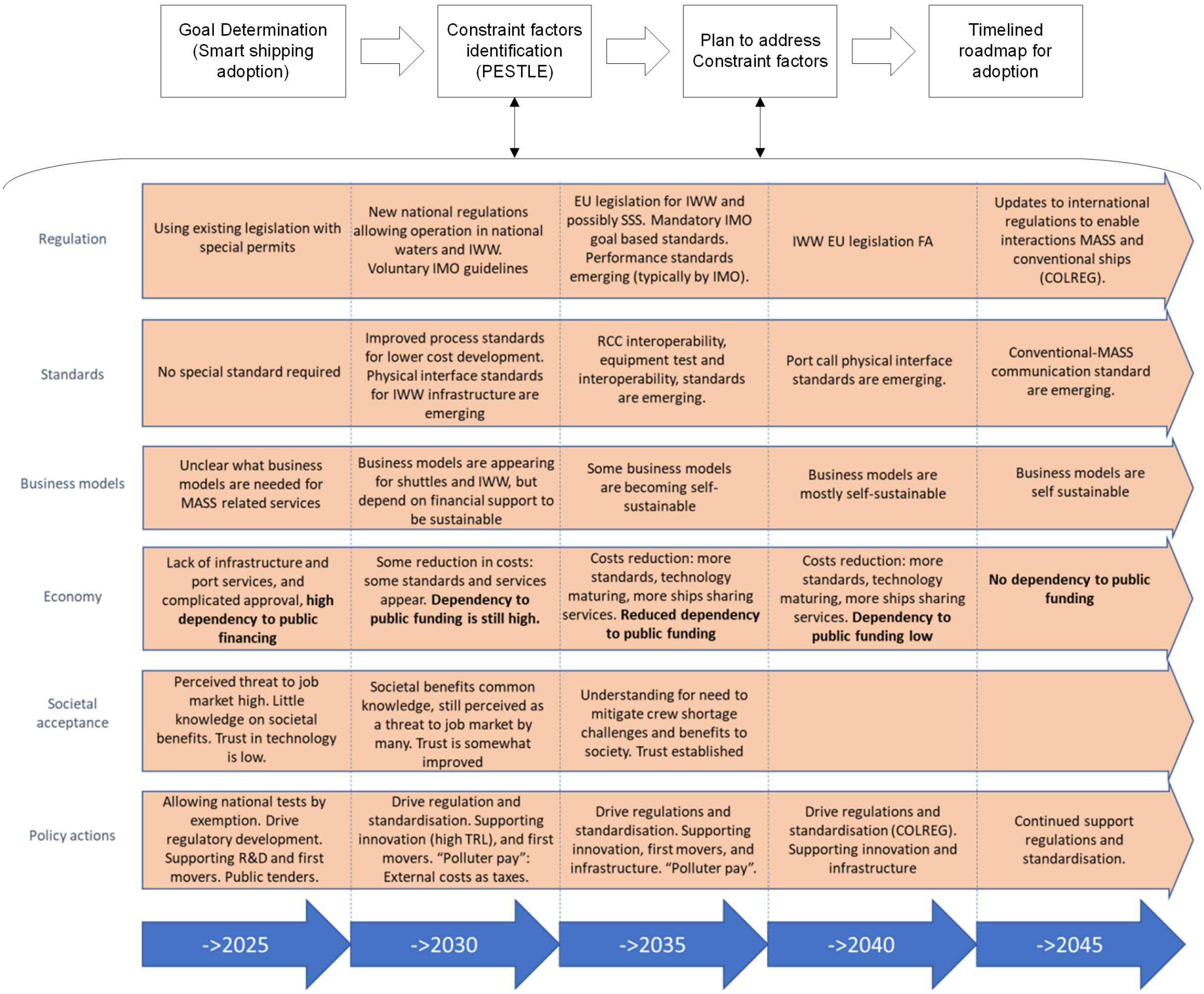

Figure 5: Constraining factors to development steps, and policy actions. Source: Nordahl et al., 2023

and reliable due to the nature of the waterways, depths, and the many fixed/dynamic obstacles that are in the way.

Martelli et al., 2021 argues that Low Earth Orbit satellites can be an alternative to communications made by artificial intelligence because they can work as a relay between the inland autonomous vessel and the possible shore station on land.

LEO satellites are the most modern form of satellite maritime communication but have a smaller footprint than geostationary satellites therefore multiple, that are configured in constellations, can be used to provide constant coverage of a selected area. LEO satellites can communicate and share data through two methods: Ship to Ship (S2S) or Ship to Infrastructure (S2I), which in this case is communicating with the land (Martelli et al., 2021).

Another type of satellite to communicate with an autonomous vessel is Global Navigation Satellite System (GNSS). Thombre et al., 2022 claims that GNSS has become the primary source of timing and position information for waterborne vessels. These satellites are primarily for accurate positioning of the vessel however, the state-of-the-art GNSS receivers vary in their capabilities depending on their target market. Receivers and antennas are mounted on the vessel where there is a good sky view so they can determine the heading of the vessel and the Position Velocity Time (PVT). Thombre et al., 2022 suggests using an Inertial Measurement Unit (IMU) integrated with a GNSS receiver to determine the roll, pitch, and heading of the ship simultaneously and to improve position accuracy under dynamic conditions.

GNSS can also be used on land for position accuracy and real-time kinematics (RTK) in instances such as port approaches where higher accuracy is needed. It is much more compatible with the maritime industry than LEO satellites as it can utilize multiple frequencies on more than one signal (Thombre et al., 2022).

Artificial Intelligence Once data is collected it must be analyzed. With Industry 4.0 becoming more apparent in industries over recent years, the use of AI must be considered when it comes to the navigation of autonomous vessels (Martelli et al., 2021). The author outlines the importance of using Machine Type Communication (MTC) for maritime communications.

Internet of Things (IoT) is deemed viable for inland autonomous shipping as it reduces the need for human operator's interaction with the vessel and increases the amount of data that can be exchanged.

IoT's are a network of physical objects that are embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems over the internet (Network, 2023).

An example is the ST4W cloud-orientated platform which provides small stakeholders with a cheap alternative to tracking and tracing their goods improving transparency while operating autonomous ships (Logistics, 2023). MTC can work with thousands of sensors at once onboard autonomous vessels and IoT can deploy network architectures for applications such as search and rescue, aids to navigation, and smart shipping (Martelli et al., 2021).

Wi-Fi & 4g & 5g Reliance on the correct system is of the most importance. WIFI and 4/5g signals are both able to be deployed rapidly to speed up the introduction of smart ships to many areas however, WIFI is limited with poor communication ranges especially when there are obstacles within these areas. 4/5g has more capacity to communicate but the network infrastructure is owned by the providers (Martelli et al., 2021) giving less control to waterway managers such as the *Rijkswaterstaat*.

2.2.2 Navigation

Navigating safely through inland waterways is one of the main focuses of shipping companies. Inland vessels constantly face limitations such as traffic and other dynamic obstacles in which the skipper must steer clear or reduce speed. If smart shipping comes with a reduction of onboard crews, then a further reliance on navigational technology will become apparent.

Radar Radio Detection and Ranging (RADAR) uses radio waves to detect and locate objects (Hassan, 2023). RADAR systems are the obvious choice for the primary long-range remote sensing on-board ships (Thombre et al., 2022). This is because radio waves can penetrate through smoke, clouds and fog where visual wavelengths struggle. RADAR devices use an emitter and a receiver to measure the Time of Flight (ToF) of pulses reflected from target surfaces (Thombre et al., 2022) to determine an object's distance, speed, and direction (Hassan, 2023). By using wide beams to scan the area the shortcomings are that it is difficult to distinguish small structural details of objects.

Thombre et al., 2022 provides two types of RADAR systems: Wave RADAR and Pulse RADAR. Wave RADAR is a continuous scanning of the area whereas Pulse RADAR sends a signal and waits for a return. Literature suggests that the currently available RADAR systems are sufficient for autonomous shipping.

Lidar Thombre et al., 2022 highlights the perspective of Light Detection and Ranging (LIDAR) systems for smart shipping. LIDAR works by emitting a laser beam and measuring the time it takes for the reflected light to return to the sensor (Hassan, 2023). LIDAR is a potent form of remote sensing that provides three-dimensional, high-resolution data that is crucial for a variety of applications, including topography, forestry, and autonomous vehicle navigation (Hassan, 2023).

LIDARs produce a detailed model of the target at various distances, but the downside is that they are susceptible to weather (Thombre et al., 2022). The downside of LIDARs is that they must operate with weak laser beams due to human safety and in the dark therefore, the range is shortened due to the reduced light.

Cameras A reliance on RADAR and LIDAR can't be absolute, there is also the need for visual sensors in the form of HD cameras. Thombre et al., 2022 defines visual sensors as all sensors that capture at least a two-dimensional image. Three types of digital cameras are proposed:

- Red-Green-Blue (RGB) - Can be used for day and night operations, depth perception, and object recognition but is limited to three colors.
- Monochrome - Ideal in open waters where there are fewer obstacles and less light is required but has a lack of color information.
- Infrared – This is the most ideal in poor weather conditions but is more expensive and has poor resolution.

Each of these camera types can be used to identify positioning, ranging, object detection, and classification however, multiple camera types should be used (Thombre et al., 2022).

Navigational Systems Marine navigational systems are essential for the safe and efficient navigation of the vessel. Maritime, 2023 have developed a new system where multiple sensors are combined with intelligent software to create the term "Intelligent Awareness". It is a navigational system that helps the bridge reduce navigational risk even through poor weather, congested waters, and at night. The system creates a 3D map of the vessel using LIDAR technology, and links with GPS data to create a better view for skippers/controllers to see beyond the limits of the human eye. These are assisted by HD cameras which have learning algorithms to determine the direction and speed of an identified vessel. (Kongsberg Maritime, 2023) state that each of these systems with the addition of RADAR and an Automatic Identification System (AIS), gives the skipper a full overview of the surroundings through data fusion. This technology is currently being applied to the passenger ferry industry in Norway but is commercially available making it applicable for inland autonomous vessels.

Mooring and Docking New technologies established for the mooring and docking of vessels are in their piloting phase. For example, the Yara Birkeland, a 120 TEU open-top container ship developed by (Kongsberg Maritime, 2023), is equipped with an automatic mooring system onboard so that berthing and unberthing can be done without human interaction and a need for extra dockside automation proposing a vast number of benefits in terms of safety and time efficiency.

2.2.3 Propulsion

With the introduction of inland autonomous ships, companies will find more value if the vessels are "emission-free" in line with their sustainability goals. For that reason, an electrical power source is researched.

Fuel Cell (Kooij et al., 2018) compares the use of a fuel cell to power autonomous vessels against conventional diesel engines. Both power generation and propulsion depend on three factors when implementing autonomous vessels: volume, weight, and cost.

Fuel cells give the possibility of a fully electric vessel and contain fewer mechanical moving parts meaning it requires less maintenance and can be left unattended. To make the ship's power and propulsion system more independent, it will be necessary to shift to either cleaner fuels or electric propulsion (Tsvetkova & Hellström, 2022). Kooij et al., 2018 compares the LT-PEMFC fuel cell with a medium-speed diesel engine and the results can be seen in Table 1.

Propulsion type	Power density kW/m^3	Specific power kW/t	Cost $Euro/kW$
Medium Speed Diesel	36-250	50-200	140-240
LT-PEMFC Fuel Cell	250-1000	300-1550	1000

Table 1: Comparison between medium-speed diesel engine and fuel cell. (Kooij et al., 2018)

It is clear from Table 1 that the fuel cell is superior concerning power output however the drawback is a higher cost per KW. Hydrogen requires large storage solutions, but because of its properties, it is suitable for shorter distances and refuelling regularly.

Electric Battery Another consideration is a fully electric propulsion system powered by batteries. Batteries have less range and higher weight than current liquid fuels (Krause et al., 2022) therefore are a less viable option for smart shipping due to energy consumption.

Research reports show that storing power sources such as batteries or hydrogen in containers helps the ease of loading and offloading at ports. This can also be supplied by other inland vessels which can transfer the power source from ship to ship creating a more standardized procedure.

In summary, technology seems to be ready to enable the uptake of smart shipping by the market and some use cases can be expected to be deployed in a short time frame Nordahl et al., 2023. And since practical tests have shown that ships can autonomously navigate around obstacles and for them to achieve full commercial acceptance in a highly competitive industry as shipping, the business gains need to outweigh the costs of implementations (Kooij et al., 2021). As pointed out by Negenborn et al. (2023): "Ships and ports are ripe for operation without humans" ... and "economic costs and benefits of ship automation and autonomy need to be established if the technology is to be taken up". In pursuing this call, the following section delves into the positive aspects to expect from this technology.

2.3 What are the benefits of autonomous shipping to inland shipping stakeholders?

Autonomous shipping has multiple benefits for inland stakeholders such as operational efficiencies, reduced costs, higher volumes, more capacities, and improved safety (Alias & Felde, 2022). It is these benefits that can drive the adoption of new technologies by shippers and port authorities.

2.3.1 Improved Efficiency

Route Planning Autonomous shipping opens new possibilities in route planning as new routes can be opened that may have not been possible for manned ships previously. Shallow waterways and complex river systems will be safer to operate through due to real-time data processing and removing the human risk element. Using data regarding currents, weather, water levels, and navigational obstacles, the vessel can make accurate decision-making and plan the most efficient and direct route. There is however still the constraint of low bridges and locks which will impact route planning to a certain degree. Most delays are caused by the operation of locks and bridges, but they form an important part of the inland waterway infrastructure (Chen et al., 2016).

State of the Art in Navigation Navigation is the largest challenge with introducing smart shipping. Full autonomous navigation is the highest level of ship navigation autonomy without human involvement all the time (Liu et al., 2022) therefore, a high reliance on the state of the art in technology is required. The technology identified above assists information sharing and is required for autonomous sailing (Krause et al., 2022).

The use of autopilot is also a consideration as it constantly cross-checks its data with other sensors and eliminates humans' tendency to rely on single sources (Burmeister et al., 2014). Incorporating the state of the art in smart shipping technology allows the vessel to analyze data in real-time and make informed decisions on the next course of action to ensure collision avoidance and optimized routing.

Cargo Handling Adopting efficient and sustainable cargo handling and storage techniques can help inland ports align with national and EU sustainability goals. Conventional vessels spend much of their time waiting to be loaded or unloaded thus they are not making money during these waiting periods. Autonomous shipping systems can cooperate with cargo management systems for more efficient loading and unloading processes and increase ship utilization through more accurate cargo planning based on cargo weight, dimensions, and distribution.

Automated Guided Vehicles (AGVs) help reduce labor costs in the port as well as combat labor shortages and improve inventory accuracy (Logisnext, 2023). Investment in electric-powered AGVs to integrate with vessels port side will improve the port's growth and efficiency consequently reducing loading and unloading times.

2.3.2 Cost Reduction

Reduced labour costs The largest and most clear benefit of operating inland shipping autonomously is the decreased crew costs concerning the number of workers onboard or operating from an Onshore Control Centre (Tsvetkova & Hellström, 2022). Direct and indirect crew costs can account for 45% of total operating costs for a Panamax bulk carrier (Kretschmann et al., 2017) which applies to smaller vessels when scaled down.

In their study, Kretschmann et al. (2017) analyze the economics of a newly designed autonomous ship according to the MUNIN project (unmanned dry bulk carrier). The main drivers for economic gains are crew reduction and improved fuel efficiency. They expect that no additional revenue will come from the exploitation of an autonomous vessel so their cost-benefit analysis purely focuses on quantifying cost-cutting opportunities in the 25-year lifetime of an autonomous bulk carrier. They summarize the cost dynamics of different subsystems and cost components in the vessel (see Table 2).

Operating costs	Voyage costs	Capital costs
Crew wages ↓	Air resistance ↓	Deckhouse ↓
Crew related costs ↓	Light ship weight ↓	Hotel system ↓
Shore control center ↑	Hotel system ↓	Redundant technical systems ↑
Maintenance crews ↑	Boarding crew for port calls ↑	Autonomous ship technology ↑

Table 2: Considered cost changes. Source: Kretschmann et al., 2017

Kretschmann et al. (2017) conclude that autonomous ships can have a positive impact on the profitability of shipping companies, and this requires crew remotion and obtaining fuel consumption efficiencies.

Kooij et al. (2021) investigate the economic viability of an autonomous cargo vessel using a short-sea container vessel through a case study. They conclude that some savings can be achieved by low manning a short-sea container ship, however, fully unmanning was found to be not economically viable. Also, the size of the monetary benefits is not as large to represent a big economic incentive to implement the studied concepts. Akbar et al. (2021) conducted a case study focused on a short-sea shipping network moving containers between Europe and ports along the Norwegian coastline. By using daughter routes to be executed by autonomous vessels and mother routes by conventional vessels in a hub-spoke network, an average operational cost reduction of 11% can be achieved. They recognize that despite this relevant cost reduction, this is dependent on the earning level of the country, in this case study, is Norway, which is a high-earning country, and acknowledging that results can differ in other low-earning countries.

Alias and Felde (2022) using a discrete event simulation studied a decentralized chain of smaller autonomous container vessels in the Rhine. Their test scenario is a feeder shuttle between inland hubs in Belgium, the Netherlands, and Germany and the main seaports in that region. They conclude that remote operation can yield 17% cost reduction whereas a fully unmanned scenario yields a 31% cost reduction. This is while maintaining vessel utilization and service levels. They expect that such findings hold in particular for closed-loop applications with recurring routes and sufficient cargo volumes. Alias and Felde (2022) also conclude that little economic information in studies may have prevented the adoption of such concepts. Ziajka-Poznańska and Montewka (2021) provide the list of open questions that remain to be answered in cost evaluations of smart shipping: costs of insurance, costs of cybersecurity, and costs of contingency operations. They also call for the need for investigation in new operating modes and business models that will be brought about by the emergence of smart shipping. The focus of this last study is not on inland shipping but on short-sea shipping.

The overwhelming majority of the above studies are focused on the maritime shipping sector (both deep-sea and short-sea shipping) and only Alias and Felde (2022) elaborate on an inland shipping container case in the Rhine. *De Vlaamse Waterweg* in Flanders and *Rijkswaterstaat* in the Netherlands have commissioned studies diving into the economic factors of smart inland shipping (Herzele et al., 2021; Panteia, 2021). Panteia (2021) acknowledge that a positive business case with acceptable levels of uncertainty is still lacking for inland smart shipping and therefore they first look at the financial feasibility of investing in smart shipping from the perspective of the inland shipping entrepreneur. They compare a baseline scenario (i.e. today's scenario) against three development paths. Findings are similar to the studies above: fuel savings and personnel savings lead to a positive business case. More importantly, not only do they evaluate the effects of switching from conventional to smart inland shipping, but they also elaborate on additional benefits, for instance, an increase in number of sailing hours, and consequently include this in the business case, as well as looking at the external effects (safety and CO2 reduction) and modal shift effects (up to 3% increase in modal shift). Panteia (2021) note that if inland shipping stops using smart shipping, the changes of a reverse modal shift will increase, as autonomous [road] driving is on the rise. Finally, an important addition to this study is the market segmentation approach used in their evaluations. For instance, different conclusions are drawn when it comes to the financial gains of smart shipping for different markets:

- Entrepreneurs of large ships have relatively greater benefits because of having larger crews and more expensive personnel that can more quickly be replaced by smart shipping. In addition, large ships sail more hours on average which means that the additional cost of smart shipping can be spread over more hours.
- For the dry bulk market where smaller crews are onboard (e.g. male/female couple) there is little incentive to reduce crew. For small vessels and small volumes, it is found that smart shipping becomes too expensive and there is little gain from the potential 24/7 operation that smart shipping is supposed to enable.

It is interesting to note that not only do these conclusions come from numeric evaluation but also upon reflection of the current dynamics of the different inland shipping markets: for instance, the predominance of a *spot* market vs. a *long term contract-based* market for tankers, the age of the fleets in the different segments, the number of competitors, the financial health of ship owners (e.g. more powerful in the tankers industry) and the recent demanded volume evolutions (e.g. the dry cargo market is experiencing declining volumes, and "the cargo volume [in the barge market] will decrease as a result of the nitrogen crisis") (Panteia, 2021).

In 2021, *De Vlaamse Waterweg* requested an economic evaluation for smart shipping (Herzele et al., 2021). The main conclusions are that smaller dry bulk ships perceive a higher cost reduction (i.e. -42%) than larger barges with continous operation (i.e. -10%). In their study they assume that "ships that sail daily or semi-continuously [... smaller ships] today can be operated remotely through automation and thus switch to continuous sailing. In the remote control center, the crew can change more easily and the ship can achieve a higher degree of efficiency without much extra cost." It is interesting to note that from a purely economic evaluation this latter study does see economic gains for the smaller dry bulk segments. In general, smart shipping provides a huge financial improvement for all the ships studied. Enabling continuous sailing with smaller vessels can play an important role in the modal shift due to the increase in competitiveness with road transport (Herzele et al., 2021).

To conclude this cost reduction section, most authors converge that there will be an economic incentive to adopt smart shipping. In most studies, these conclusions emerge after comparing baseline reference scenarios (i.e. current scenario) and then replacing the current operation with smart ships and then performing a cost comparison. Some studies such Alias and Felde (2022) and Herzele et al. (2021) focus in inland shipping and even incorporate economic gains for indirect benefits, for example, by transporting more cargo for longer time with smaller smart ships. In adition, unmanned vessels bring the opportunity to operate 24/7 now that the limitations of labor working hours and crew fatigue are out of the picture. This increases route optimization, especially for contract operators who often use the same route each week. Reducing the downtime of vessels allows for faster delivery times and more journeys to be carried out leading to higher revenues.

Slow steaming The motives behind unmanned and autonomous ships include the shortage of skilled mariners and the facilitation of slow steaming strategies (Burmeister et al., 2014). Slow steaming directly relates to reduced fuel/energy consumption and cost, made possible by autonomous shipping alongside a reduction of gasses from the exhaust. If there are few/no crew onboard the vessel, then the bulk of the labor costs are roles carried out on the shore. Slow steaming is beneficial for stakeholders when short lead times are not a priority and emission reduction aligns with the goals of the organization. A shortage of skippers made this method originally unrealistic. Slow steaming also extends the life of the engine due to less pressure exerted than at high speeds, reducing the levels of maintenance required.

Maintenance and Repairs Autonomous vessels can be designed with more simplified systems so that less maintenance is required. Less maintenance personnel will be required and more time will be saved in repairing such mechanical issues. With systems fitted to monitor vessel performance, more accurate predictive maintenance measures can be achieved to reduce the chance of an unforeseen error directly leading to reduced costs.

Improved logistics The value creation of autonomous surface ships depends on the degree to which they can disrupt logistics (Tsvetkova & Hellström, 2022). Throughout the literature, there are various definitions of autonomous shipping and how each level is defined but they all to some degree range from the current conventional human-operated methods to remote control and end at full autonomy.

A simulation conducted by Alias and Felde, 2022 along the Rhine and Weser rivers, comprises operating smaller vessels on more frequent routes to achieve higher utilization of each vessel. The Discrete Event Simulation (DES) runs between two points that consider the entire area of both rivers based on 4 main KPIs: costs per TEU kilometer, service level, capacity utilization, and time.

The cost comparison shows that fully autonomous operation is the most cost-effective option for inland waterways in the Hinterland of Dutch, Belgian, and German deep sea ports. The capacity utilization and service level for remotely monitored and fully autonomous operation still uphold the same level in this simulation. Fully autonomous inland vessels are the most effective for this region due to the improved logistics of route optimization.

2.3.3 Increased Safety

One of the biggest questions about operating inland shipping autonomously is, is it safe? Through research, it is shown that if autonomous vessels are to be accepted, they need to be as safe as or safer than current vessels. Increased safety is achieved by the creation of new concepts for maintenance and operation as well as improved applications for navigation (Burmeister et al., 2014). By incorporating state-of-the-art technologies with the addition of new technologies in the future, navigational safety is improved by the reliance on systems rather than humans due to constant and advanced situational awareness brought by ship intelligence (Tsvetkova & Hellström, 2022).

A study by Chen et al., 2016 shows that operational error proves the largest cause of shipping accidents in Dutch inland waterways mainly linked to alcohol/drug use, wrong estimation, and fatigue. These each constitute human error with fatigue being a common factor throughout this research. Fatigue has been claimed to cause 75–96% of accidents at sea (Tsvetkova & Hellström, 2022) therefore, by reducing/removing crew from the vessel and into a remote control center, automatic systems will take on routine tasks that call for abilities that humans are not best suited for such as extended periods of vigilance (Burmeister et al., 2014).

2.3.4 Additional Capacities

The removal/reduction of the crew from the vessel also gives more operational decisions now that the safety of the onboard crew is no longer considered. This allows ships to be designed differently with improved air and hydrodynamics as well as being lighter with less ballast water required (Tsvetkova & Hellström, 2022), which has a direct impact on the environment and capacities.

There will also be no longer a need for the bridge control room due to operations being outsourced to a remote center or the full reliance on systems. It is possible to use the space more efficiently without needing any crew accommodation (Krause et al., 2022) such as sanitary facilities, cooking facilities, or sleeping dorms. Removal of these structures will help make the ship more aerodynamic with improved airflow leading to significantly reduced fuel costs.

With additional capacity available on the vessel, combined with an opportunity for new vessel designs, this allows for more cargo to be transported and/or creates an area for new fuel sources such as fuel cells to be stored. More capacities are directly linked to increased revenue potential, and operating efficiency and prove a more competitive business case for ship owners to adopt.

2.3.5 Environmental Benefits

The opportunity given of new ship designs and the use of cleaner energy sources play a role in reducing the environmental impact of inland waterborne transport. Autonomous vessels also have the chance to remove the inefficiencies in current logistics resulting in a reduced environmental impact on cargo transportation

(Tsvetkova & Hellström, 2022). A combination of these will align perfectly with national and EU targets of cutting greenhouse gas emissions by 55% by 2030 (for Climate Action, 2023), alongside the sustainability goals of barge operators and terminals.

2.4 What influence does autonomous shipping have on human participation?

2.4.1 Answer to shortage of skippers

One of the reasons autonomous ships can have a big relevance in the societal dimension is that it can be the answer to the increasing challenges related to the recruitment of skilled crew (Nordahl et al., 2023). According to Pauwelyn and Turf (2023), there is an international consensus that the automation of inland vessels can help alleviate the shortage of skippers. Working as a remote captain or traffic controller can allow the worker to use 8-hour shifts and return home at the end of the day, which is not always possible with the current operations setups.

2.4.2 Reduction of Crew

Autonomous shipping has a direct relationship with reducing crew levels. Depending on different parameters such as ship size, operating hours, and safety, manning levels can vary in quantity.

Ringbom, 2019 views autonomy in two relative and standalone elements: Manning levels and levels of autonomy. Manning level is judged by the location of the crew if the vessel is remote-controlled from the shore or controlled from inside the vessel's bridge. The level of autonomy is decided by which extent tasks are carried out by humans or machines. For example, a remotely controlled ship operating at the third degree of autonomy is not, strictly speaking, operating autonomously if a human navigator is making decisions from a shore-based control center (Tsvetkova & Hellström, 2022).

Ringbom, 2019 depicts a simplified two-dimensional figure to compare both elements as shown in Figure 6. The vertical axis addresses the level of onboard manning, whereas the horizontal axis addresses the level of autonomy. The blue arrow indicates the shift from conventional inland shipping to fully autonomous unmanned operations.

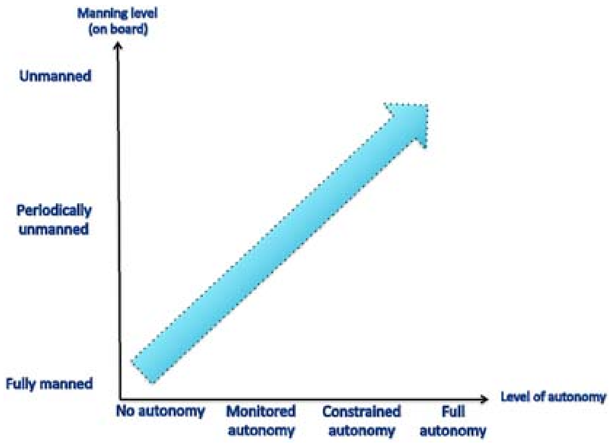

Figure 6: Comparing manning levels with the level of autonomy. (Ringbom, 2019)

2.4.3 Shift in Skill Requirements

As manning levels will be reduced due to the introduction of smart shipping, the question lies, How will the ships be controlled? A remote control center is proposed to bridge the gap between conventional operations and full autonomy.

Organizations such as Seafar, 2022 have already started using control centers to operate autonomous vessels. This creates the case for remote operations involving the external control of the ship with full reliance on sensor equipment onboard the vessel (Alias & Felde, 2022) alongside each of the other technologies mentioned in this paper. A remote control center will be primarily for fleet management creating flexibility and efficiency (Krause et al., 2022) while monitoring self-state information such as position, speed, and heading (Chen et al., 2016). Over time there will be less requirement for skills from the skipper and more of a reliance on expertise from controllers therefore the reliance on fixed and temporary crews will be significantly reduced.

These skills will require one human operator to supervise several ships of alike type to facilitate familiarisation. The operator will take control as soon as any deviation from the planned course is indicated so it can be handled at an early stage. In case of an emergency or situation that cannot be solved by an onshore control operator, a situation room with a specially trained bridge team will take full remote control to avoid dangers to the ship or other vessels (Burmeister et al., 2014).

The use of a remote control center proposes a higher risk of cyber security which must be considered while investing (Krause et al., 2022). Skills based on IT systems and coding algorithms will be required to ensure security.

2.4.4 Training of Workforce

While inland ports must make changes to prepare for smart shipping, there needs to be a trained workforce in place to carry out the human-required tasks. Remote and autonomous operations will transfer many seafaring jobs to land-based control centers, opening the industry to a new set of people who will find a maritime career, onshore, a more attractive proposition (Kim et al., 2020).

There needs to be a supply of workers to operate the remote control center, therefore, a curriculum for the next generation of inland shipping personnel must be determined. This will require adaptation by maritime colleges, including employing new staff, and it also calls for "on-the-job" training curricula to train current crews in new skills or new jobs (SMASH! 2023).

Trained cyber security analysts are needed to ensure the safety of autonomous operations. Maintenance personnel require further training in working with new technologies. Stevedores and marine operators will also require training in the short term to work alongside newly developed automation systems throughout the introduction phase.

2.5 Final remarks of the literature search

An investigation of the published literature was conducted to identify the most recent and relevant information on the adoption of autonomous shipping to inland logistics. The review offered the basis for the empirical phase of this research by presenting the Diffusion of Innovations theory created by E. Rogers (1995) and the Technology-Organisation-Environment (TOE) framework proposed by Tornatzky and Fleischer (1990). Other models have been proposed and tested by Fonseca et al. (2021), Nordahl et al. (2023), and Park et al. (2022) and the notion is very similar across these studies: to be adopted by practitioners, autonomous shipping must be technically possible, it must be legal to operate, the sufficient infrastructure needs to be in place, it should be as safe as conventional shipping and it must be sufficiently profitable.

Sections 2.2, 2.3 and 2.4 were organized based on inspiration taken from the model proposed by (Fonseca et al., 2021) highlighting which parameters must be met for autonomous technology to take place. The state-of-the-art technologies applicable to autonomous inland shipping are identified, broken down, and stated within communication, navigation, and propulsion based on their use. Furthermore, inspiration is taken from other projects such as the Yara Birkeland, which presents these technologies in actual application, and literature keeps growing arguing that the technology is ready to be implemented in actual cases (Kooij et al., 2021; Negenborn et al., 2023; Nordahl et al., 2023).

For adoption to take place there must be a business case and investors need to see a perceived benefit. Therefore the benefits that smart shipping brings are identified and broken down in an economic and logistical context. The findings include improved efficiency, cost reduction, increased safety, additional capacities, and environmental benefits. In a holistic sense, the reduction of crew onboard the vessel along with new ship designs allows for a multitude of benefits for the relevant stakeholders.

Lastly, the human aspect is investigated and what impact autonomous shipping has on human participation. Through desk research, it is found that smart shipping brings a reduction in manning levels onboard the vessel along with a shift in skills towards remote-controlled operations to combat labor shortages of the skipper. A spotlight is also brought to how the staff for these "new roles" will be supplied.

The findings from the literature review act as a solid base for proposing a new model to the industry in Zeeland so that suggestions can be made on who will want to adopt autonomous shipping first and how this will be applied. An adapted version from the model proposed by Fonseca et al., 2021 is shown in Figure 7.

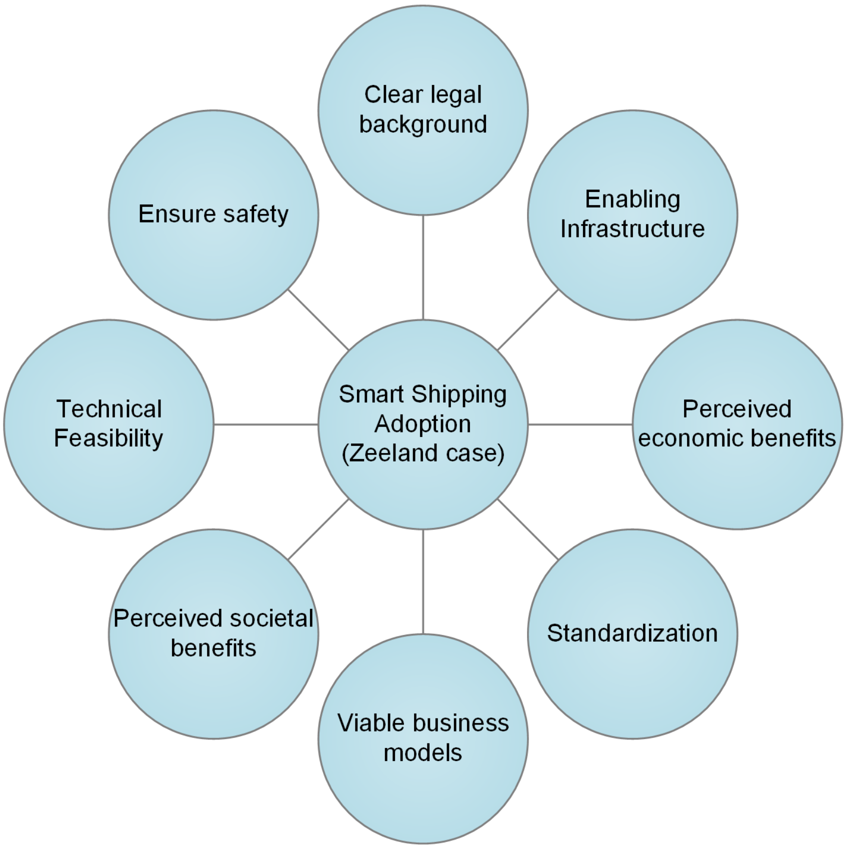

Figure 7: Adoption model adapted from Fonseca et al., 2021; Nordahl et al., 2023; Park et al., 2022.

3 Research Method

Throughout this research, a mixed-method strategy will be taken. Qualitative data will be gathered through interviews with technology experts and Zeeland terminals representatives so that all criteria for autonomous shipping adoption are covered. An inductive approach will be used to identify the findings of this primary data collection. Quantitative data will be collected using datasets provided by North Sea Port to gain an understanding of goods flows in and out of Zeeland for the basis of this study.

3.1 Research Process

To conduct qualitative research the process will involve first identifying the key areas to be researched which in this case will be autonomous shipping in Zeeland. Secondly, sub-topics will be chosen, taken from the theoretical framework, and a research objective will be selected. The quantitative research process will involve analyzing datasets and filtering the relevant parts so that findings can be made. The theoretical framework of this research is shown in Figure 8.

3.2 Research Context

The shipping industry in Zeeland is a growing industry involving inland and short-sea shipping operations with goods inbound and outbound from the North Sea, North Sea Port, The Scheldt, and The Rhine. Liquid bulk, dry bulk, and containers each make up these flows and it is unclear who will be first to adopt smart shipping technology in Zeeland due to the lack of research and gathering of opinions from the stakeholder's

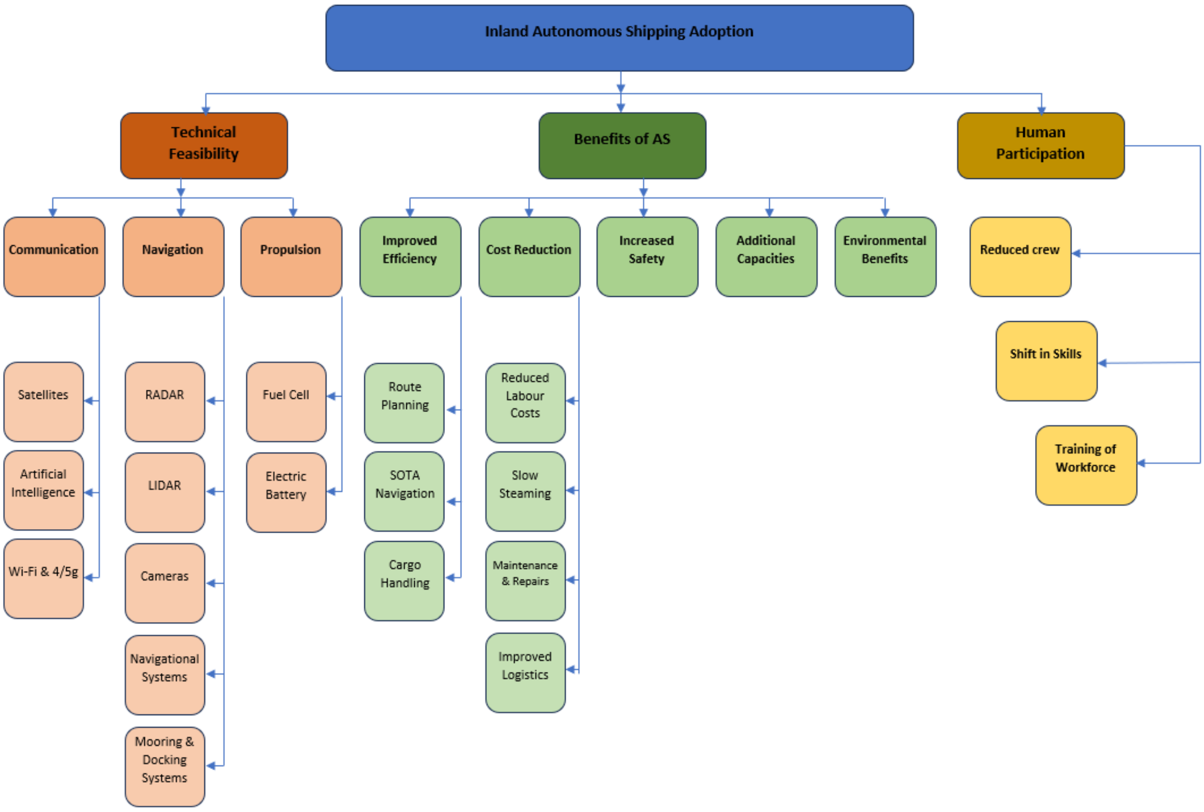

Figure 8: Theoretical framework

perspective. There needs to be a spotlight on terminals, barge operators, and technology developers to find out where the gaps are present and what the drivers are behind smart shipping technology adoption.

3.3 Data Collection Methods

Quantitative operational data is to be collected by one of the partners of this study from the North Sea Port organization. There will also be data collected using the *Kostentool Binnenvaart* provided by (Rijkswaterstaat, 2023) to analyze the related costs of inland shipping currently so comparisons with autonomy levels can be made. Datasets concerning goods flows to and from North Sea Port will be needed so that a route for each industry type can be made based on real-world operations.

Qualitative data will be collected through primary interviews based on 3 guidelines: technology development, technology application, and industry adoption.

To obtain opinions and perceptions on the technologies that are applicable to inland autonomous shipping in Zeeland, semi-structured interviews will be conducted with active technology developers in the smart shipping industry.

Companies such as NTNU and Captain AI will be targeted for semi-structured interviews to find out how the technology is being adopted in other locations. SeaFar who operate remote control inland vessels from their remote control center in Antwerp will be questioned to find which aspects of their business can be adapted to Zeeland, which is less than 20km away.

Semi-structured interviews will be conducted with three Zeeland terminal representatives. Each terminal must operate at least one of the selected industry types of liquid bulk, dry bulk, and containers. Ideal terminals are Vlaeynatie, Dow, OVET, and/or Bulk Terminal Zeeland to discover their thoughts on this new technology and identify which benefits and limitations there are from their perspective. They will also be interviewed to gather information about vessel owners as they operate with a wide array of vessel owners so a combined consensus from an entire fleet can be gathered rather than just one barge owner. The end goal will be to get a sense of the expected rate of adoption from their perspective. Respondents will be accessed via LinkedIn and email to find experts in these fields.

3.4 Data Analysis Methods

Data condensation is the process of making our gathered data stronger (Creswell & Creswell, 2018). This will be done by inductive coding. Each interview will be recorded and transcribed so that further analysis can be done by coding to assemble large chunks of information together and gather the most meaningful content. It is expected that with gathering thoughts and opinions from experts in the field there will be similarities and differences. This will have to be accounted for when coding and ensure that each argument is taken into consideration when drawing findings.

Quantitative data will be analyzed by preparing the data, gathering relevant statistics, and visualizing through graphs and charts so that relevant data is clear and solid. This will be built over the theoretical framework so that findings are applicable and specific to Zeeland.

3.5 Quality Criteria

Construct Validity mentions the extent to which the study or test, measures or investigates what it claims to measure or investigate (Yin, 2009). This will be achieved by choosing the appropriate literature about autonomous shipping and the impacts it has on logistics. Recent and reliable sources such as ongoing technological research in Norway and relevant logistical theories worldwide will be used and applied to a real-world example, in this case, inland shipping in Zeeland. Anything outside of this project's scope will not be included in this research unless it has a direct impact on the research questions.

Internal validity will be controlled by comparing the explored literature with the stakeholder interviews and comparing results so that the study aligns with the needs of the users.

External validity is acknowledged as a challenge since, by design, the study has a relatively small sample size for interview responders. This will be remediated by using a well-represented set of responders from different sectors and by using well-known theories and models to build upon, which will help generalize the results.

Research reliability will occur by ensuring interviews are carried out correctly in the sense that each question is properly structured, and understood by the interviewees and that relevant answers are given. Archived documents will be tested for their internal reliability during the data collection phase. Smart shipping technology is continuously developing therefore this research is based on current available data and may be influenced in the future by new technological advancements.

4 Results

In this section, the quantitative findings from data provided by North Sea Port and the Rijkswaterstaat alongside qualitative data provided through interviews with relevant stakeholders are analyzed and presented.

For the collection of primary qualitative data, five interviews were conducted based on the different aspects looked at throughout this research. Appendix A for the data condensation of the interviews conducted through coding.

- Captain AI- A software developer based in Rotterdam focused on autonomous shipping technology.
- SeaFar- Developers in technology and remote-control center operators in Antwerp.
- Dow Terneuzen- A Zeeland-based chemical producer in Terneuzen who loads and unloads inland tankers to serve their B2B operations.
- OVET- A Zeeland-based Dry Bulk terminal in Vlissingen and Terneuzen that tranships mainly black dry bulk products such as coal.
- Vlaeynatie- A Zeeland-based company that provides logistics for containers and dry bulk products alongside value-adding activities in the supply chain.

An intermediate data exploration analysis is performed to understand the inland shipping market segmentation in the region of Zeeland.

4.1 Clustering and Statistics of North Sea Port terminals

The input data used for this analysis consists of Inbound and Outbound movements performed in the North Sea Port, specifically in the ports of Terneuzen and Vlissingen, in the time frame of January 2020 and December 2022. The steps conducted to clean and recode the original dataset and to split the data into market segments using a K-means clustering algorithm with the approach developed by Huang, 1998 are available to the interested reader upon request.

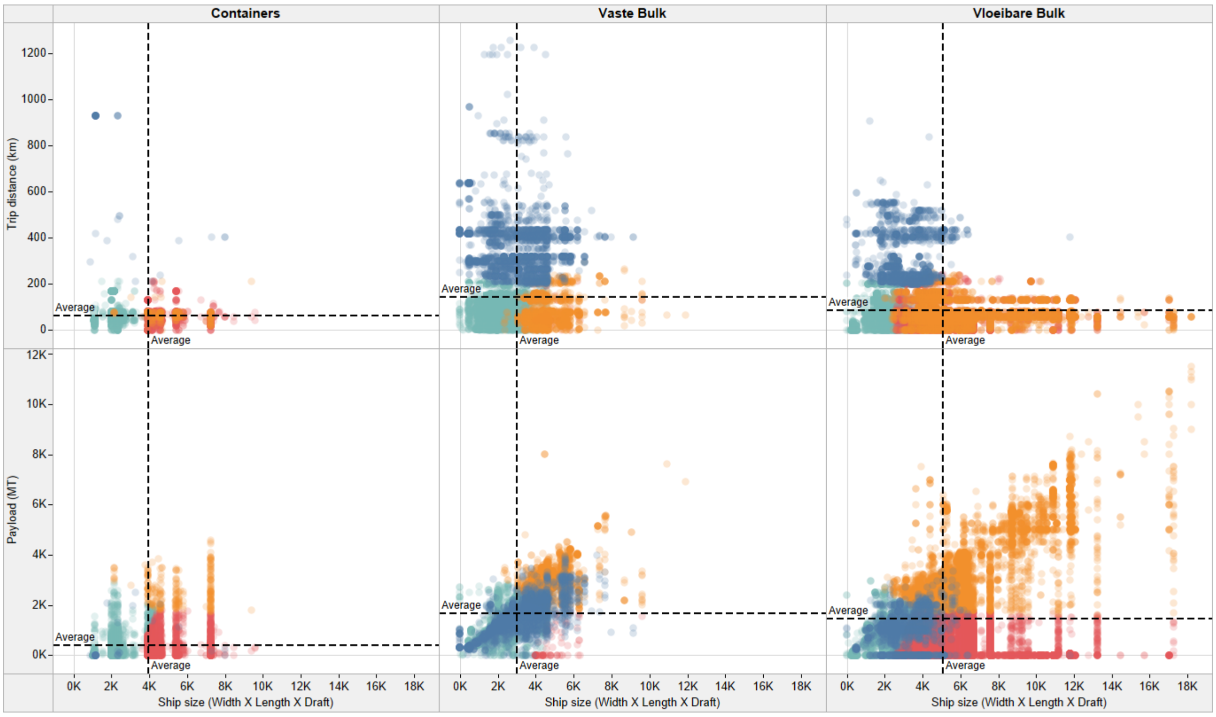

Figure 9: Relationship across Clusters - Cargo type

Figure 9 and 10 display the data-driven identified clusters:

- Blue (0): Long distances, both liquid and dry bulk with a wide range of payloads and barge sizes
- Orange (1): Short distances, large vessels and payloads, any cargo type and any product
- Red (2): Large tankers and container vessels. Mostly petroleum-based, chemicals and miscellaneous products
- Green (3): Short distances, smaller barges, medium to small payloads. All cargo types.

Other studies have also proposed a set of clusters to be able to understand the different implications of smart shipping and suggest adoption roadmaps. Nordahl et al. (2023) define 4 major shipping groups:

1. Sheltered water shuttles (can be inland or short-sea shipping use cases)
2. Inland waterways
3. Short-sea shipping (in international and long-distance national waters)
4. Deep sea shipping

In our study, the Orange (1) and Red (2) clusters have more proximity to one another and this can represent large barges (tankers, dry bulk, and containers) that travel medium to lower distances. Cluster Blue (0) represents long-distance movements of dry and liquid bulk. This can be with smaller, medium, or large barges. Cluster Green (3) represents smaller vehicles carrying smaller payloads and shorter distances. Barges in this cluster carry bulk as well as containers.

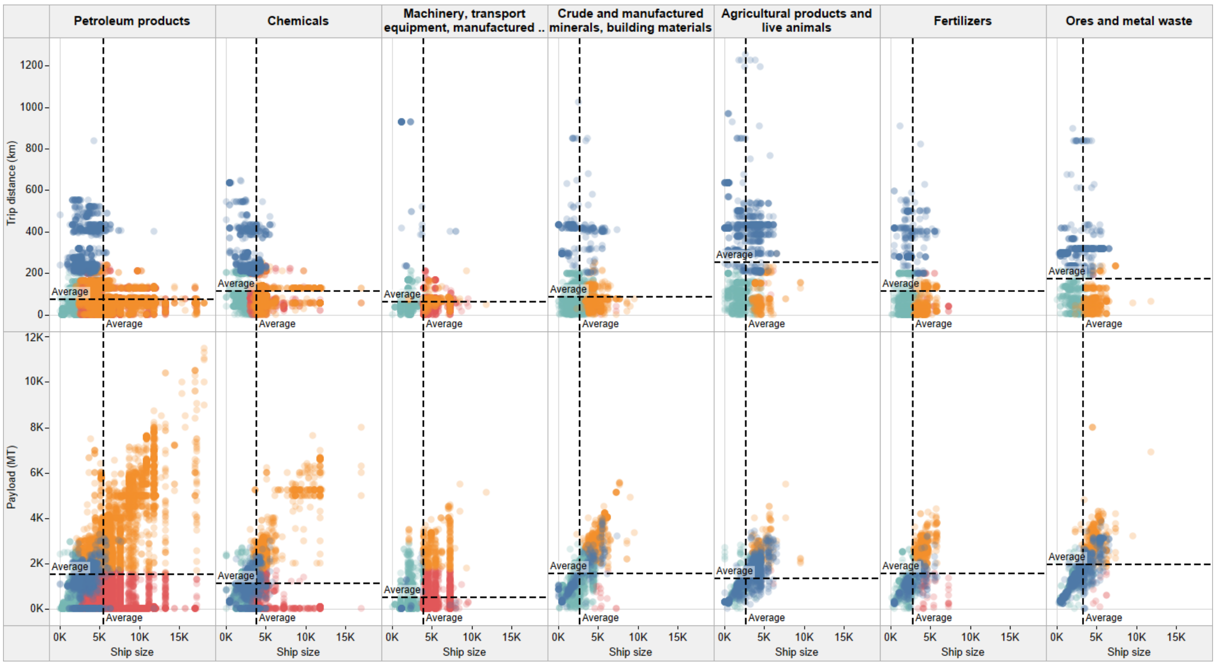

Figure 10: Relationship across Clusters - Product

Submarkets	Entrepreneurship type	Contract type
Dry cargo ships	Family business	Spot market
Sand and dredging sludge ships	Cooperative	Time chartering
Liquid cargo ships	Shipping company	Permanent contract

Table 3: Fleet subgroups per Panteia (2021)

Panteia (2021) suggested a multidimensional segmentation based on submarkets, entrepreneurship type, and contract type. This segmentation is displayed in Table 3.

In the rest of this study, groups will be assumed based on cargo type (i.e. Containers, Dry bulk, Liquid bulk), for instance, one of the market segments to be evaluated is containers. Containers mostly travel in and out of Zeeland to the closest seaports, i.e. Rotterdam and Antwerp. These ports are located less than 150 kilometers from the North Sea Port terminals. Another distinctive group is the liquid bulk (i.e. tankers) and the dry bulk.

As shown in Figure 11, the flows out of the harbor of Vlissingen are emphasized on outbound cargo when compared to inbound flows. This means that there is more cargo coming out of Vlissingen than the cargo coming in. The situation in Terneuzen is different as both flows seem to be compensated. In terms of evolution, there do not seem to exist striking upward or downward patterns in the amounts of cargo coming in or out of the region via the North Sea Port terminals by ships.

When splitting the data per material categories, it's visible that the categorization of container cargo is only visible at the empty/loaded level. In Figure 12, it can also be the imbalance of empty vs loaded containers, meaning that in Zeeland, an amount of empty containers need to be brought to fulfill the container outbound needs.

In addition, a major volume player of the dry bulk volume is the cargo of sand and gravel. This particular segment has been addressed by Panteia (2021), as a market that is made of mainly obsolete ships but with some new additions in the fleets. A second product type used in the dry bulk segment is the transport of coal and paper. (Figure 12).

The top products for the liquid bulk market (tankers) are mainly oil-related products (fuels and oils) and basic chemical products. These are shipments with an average of 2000 MT and typically go back and forth between Zeeland and the seaports of Rotterdam and Antwerp (Figure 12).

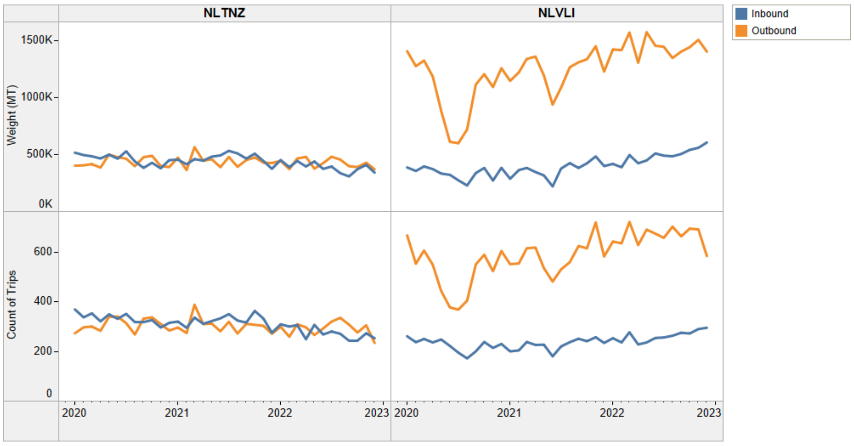

Figure 11: Inbound vs Outbound balance (by Cargo weight MT and Count of trips)

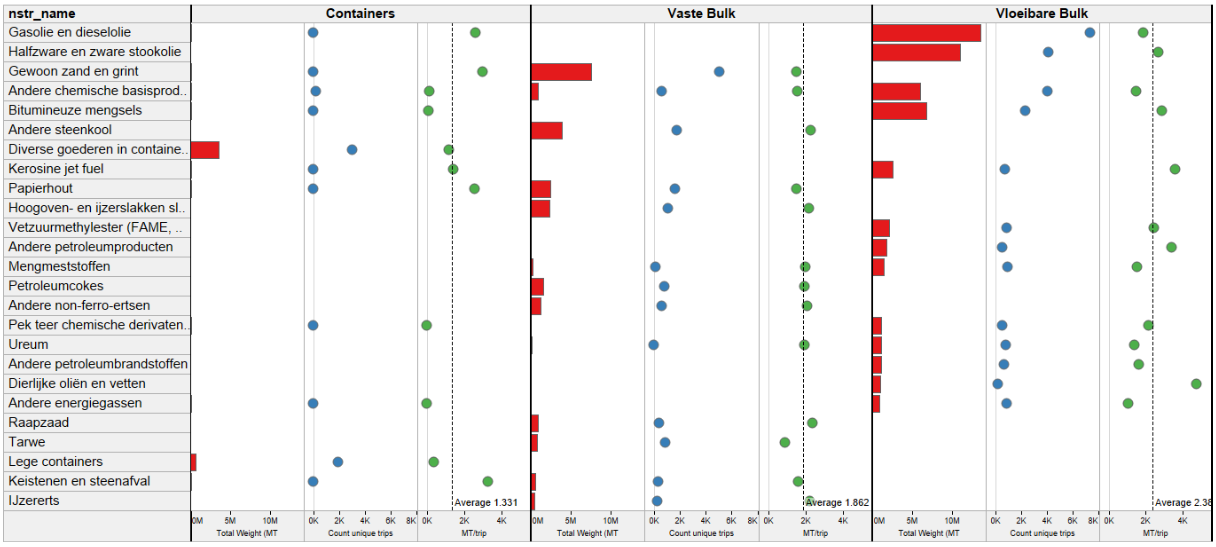

Figure 12: Top 25 Material categories (by Cargo weight MT)

In addition, to best explain the findings of each empirical question, three routes are investigated to assess and apply the technical feasibility, economic benefit, and human capital required for technology adoption. Each route is between a North Sea Port in Zeeland and a frequent destination for the given market analyzed from data provided by North Sea Port and interviews. Routes that are outbound from Zeeland generally carry transhipped goods from short/deep sea vessels or goods produced by local companies such as Dow. Within each route are navigational barriers such as locks and bridges which may be barriers depending on water levels and the height of the vessel.

Routes 1 and 2 are found to have communicational barriers for autonomous shipping because they pass through multiple countries with various network providers creating weaknesses in signal strength at border areas where networks need to be switched. Currently, autonomous shipping is not allowed along any sections of these routes which is why they have become a focus in this research.

Each of the selected routes is shown in Table 4. Each of these routes will serve as a base for applying and testing each aspect of the theoretical framework.

4.2 How can autonomous shipping technology be applied to the logistics domain in Zeeland?

By using secondary research as a foundation, the key technological theoretical concepts were compared with the interviews with technology developers and users such as Captain AI and SeaFar. Both parties

Route Nr.	Origin	Destination	Industry	Country	Num. Locks	Num. Bridges	Distance (km)	Duration (h)	Tidal Sections
1	Terneuzen	Basel	Liquid Bulk	NL, DE, FR, CH	13	50	904	70	Western Scheldt
2	Vlissingen	Duisburg	Dry Bulk	NL, DE	3	16	309	23	Western Scheldt
3	Vlissingen	Rotterdam	Containers	NL	3	9	171	8	Western Scheldt

Table 4: Selected Routes for Applying Empirical Research. Source: Authors

were interviewed to figure out which parts of literature are valid in the region of Zeeland alongside obtaining new insights. In addition to this, each company that was interviewed based on the several industry types was also questioned about what they feel is needed from technology to accommodate autonomous shipping, and their opinions were documented.

4.2.1 Communication

4g and 5g For AS to work in practice, there must be a strong and consistent internet connection throughout all aspects of the operation. In an interview with Vlaeynatie, some key concerns are around how different network providers operate in each country. It has also been identified that close to the border between countries there is poor internet coverage therefore if sailing must rely entirely on 5g internet networks there will be interruptions in the connection which may lead to collisions or leaving the vessel static in the water causing a hazard to navigation.

Artificial Intelligence From the literature, it has been found that MTC, in particular, IoT, is viable for data analysis in inland shipping. In practice with SeaFar, IoT is useful for using sensors as input and steering as output. Multiple sensors are processed onboard the ship using AI and communicated via a cloud platform. Data from AIS and RADAR is processed by machine learning-based AI via sensor fusion. Collectively, all analyzed data is sent to the control dashboards of the human controller which monitors the vessel's data and intervenes when necessary.

4.2.2 Navigation

Satellites A combination of satellite and internet networks is advised by Captain AI. Internet networks should act as the primary source of data sharing due to the relatively low cost to implement and ease of use supported by backup satellite systems which can immediately take over when the connection fails. It is found that both GNSS and LEO satellites are sufficient via Starlink because the ship should still be able to man itself when the signal drops.

In contrast to this, SeaFar don't use satellites and they operate remote control vessels currently in Flanders, Belgium therefore in Zeeland, it comes down to the quality of the network signal and how the networks of different countries can be incorporated and switched.

Maps and GPS Location data from GPS is crucial for navigation as the position of the vessel must always be known. Autonomous vessels require constant tracking and monitoring to avoid collisions so if they are stopped dead in the water the location is communicated to nearby vessels. SeaFar applies this technology by creating geofences which are waypoints that once a vessel reaches its waypoint, will stop and wait for the next assignment. For the three routes investigated in this paper, this will be viable for the locks of Hansweert, Krammer, and Volkerak. For Route 1 representing liquid bulk, additional value is brought by this for the additional locks upstream in the Rhine. Geofences should also be made for areas that are tidal for instance, the Western Scheldt, where water levels have a direct relation to low bridges.

Radar Through literature, RADAR is used to detect and locate objects. This applies to inland shipping in Zeeland as due to its proximity to the north-sea, there can often be poor weather conditions with fog reducing the visibility of the skipper as well as night operations. Primary research shows that RADAR is ideal for this as it is used alongside visual data from cameras to further improve awareness of the surroundings and collision avoidance. Wave and pulse are both useful means of scanning the surroundings of the vessel to detect objects and other vessels.

Lidar LIDAR will also be required for autonomous inland shipping in Zeeland. Due to its short ranges, it is most useful for areas where the vessel is close to the shore, such as in one of the locks. It will also be necessary for the port area alongside mooring and docking systems to ensure a maximum amount of scanning and safety. LIDARs aren't as effective in poor weather and therefore cannot be solely relied upon.

Cameras The use of imaging sensors will be heavily relied on going forward. It is the key component to remote operations and the first thing a controller looks at when monitoring the vessel. Throughout interviews with relevant stakeholders, the usefulness of this type of technology has been validated by SeaFar who gave an in-depth description of which cameras are ideal. Stereo vision cameras integrate high-resolution camera sensors plus infrared sensors for distance measurement. Using stereo vision cameras, a 3D view is capable, but they do endure high costs for adoption as infrared sensors are more expensive but if technology improves and makes these cameras more accessible then they could be a core sensor in AS (Thombre, S. et al., 2022). Subsequently, SeaFar has chosen to use a set of IP cameras that offer a high-resolution, real-time video feed with night vision and are robust. This approach includes less costs and is used in combination with RADAR and AIS for added situational awareness.

Automated Mooring Automated mooring is thought to increase safety and reduce human error during the parts of the route that have the largest risk of collision i.e. mooring and docking. Inspiration from Yara Birkland's mooring system was taken from literature. Interviews conducted with Zeeland terminals from all 3 industries found that they are in favor of assisted mooring and docking systems but not fully unmanned. This is not welcomed or supported by terminals because if an accident occurs then who will be left responsible and liable?

Navigational systems It is found that navigational systems are going to be required to some degree. The use of track pilots, automatic report following, and automatic identification target systems are highlighted to be used in the industry now in Belgium. There can't be any reason found for why this won't work in Zeeland provided that Dutch waterways can withhold the infrastructure to support it. Literature suggests that the intelligent awareness system is evident for short-sea shipping and can evidently be applied inland to the Western Scheldt and the Rhine.

4.2.3 Propulsion

There has been a questionable gap found within the primary data-gathering process in terms of how autonomous vessels should be propelled. On one side there are the technology developers who don't seem to have much of a priority on sustainable fuel sources. They believe that fossil fuels will still be used for the rollout of smart shipping in Zeeland as they require less storage than a 20ft battery container, as mentioned by SeaFar. If the vessel can move forward and steer, then there is no further priority. On the other side, there are industries that are expected to adopt autonomous shipping and have their own individual sustainability goals to fulfill, in line with the EU and national regulations. The findings are that industries in Zeeland will gain much more benefit from sustainable fuel sources and fuel cells are found to be most ideal alongside being favored by each industry therefore, this should be the propulsion method applied.

Each of the above technologies combined apply to operations in Zeeland but adoption is limited by legislation, safety, and the willingness to adopt by the relevant stakeholders.

4.3 How can autonomous shipping provide an economic benefit to operators in Zeeland?

In this section, the findings are shown of how smart shipping can provide an economic benefit to operators in Zeeland. The most important goods flow to focus on is first identified followed by a breakdown in the economic aspects of smart shipping: cost reduction, improved efficiency (revenue), and investments.

4.3.1 Cost Reduction

In this section, the annual operation costs are broken down per industry per selected routes. Similarities and differences from an economic perspective are identified and grouped to assist in reaching a clearer consensus.

A similarity has been found in the liquid and dry bulk routes as they both have high frequencies of voyages departing North Sea Port and sailing up the Rhine and unloading at Germany and Switzerland. For this reason, these routes have been synergized for the input of the cost model. Using data provided by (North Sea Port, 2023) and the “Kostentool Binnenvaart” provided by the (Rijkswaterstaat, 2023), Dutch waterway authorities, an estimation is made to the annual costs of the chosen IVa M6 Rhine-Herne Ship. The selected vessel is chosen due to its compatibility with each of the indicated cargo industries alongside its ability to service Dutch Inland Waterways and the Rhine. For further information see Appendix 9 and Appendix 10.

The estimated annual operating costs for each industry type are broken down into multiple subsections so it can be shown which aspects add up to the largest costs. The costs account for continuous 24-hour operations of a loaded vessel along each route. The results are shown in Tables 5, 6 and 7.

Total Cost per Year (Euro)	Conventional Operation	Remote Operation	Fully Autonomous Operation
Insurance	48.215	40.018	32.786
Repair & Maintenance	34.130	28.328	23.208
Interest	32.181	26.710	21.883
Port charges	9.531	7.911	6.481
Wage	398.978	331.152	271.305
Fuel	123.126	102.195	83.726
Other	11.988	9.950	8.152
Total Annual Costs	**658.149**	**546.264**	**447.541**
Savings		111.885	210.608

Table 5: Annual Operational Costs for M6 Liquid Bulk Vessel on the Rhine. Source: Rijkswaterstaat (2023), Author

Total Cost per Year (Euro)	Conventional Operation	Remote Operation	Fully Autonomous Operation
Insurance	16.200	13.446	11.016
Repair & Maintenance	29.929	24.841	20.352
Interest	10.023	8.319	6.816
Port charges	12.296	10.206	8.361
Wage	384.961	319.518	261.773
Fuel	122.337	101.540	83.189
Other	11.988	9.950	8.152
Total Annual Costs	**587.734**	**487.819**	**399.659**
Savings		99.915	188.075

Table 6: Annual Operational Costs for M6 Dry Bulk Vessel on the Rhine. Source: Rijkswaterstaat (2023), Author

The largest costs in inland shipping currently are crew wages and fuel. Since an increase in the level of autonomy equals a decrease in manning levels, wage costs will significantly reduce. The opportunity of slow steaming by removing crews, or at least reducing the dependability on the crew through remote operations, will allow for reduced fuel consumption. Slow steaming also reduces maintenance since less pressure is exerted on the propulsion system. It is not yet clear to which extent crew will be reduced and how much of a fuel saving can exactly be made on these routes as both levels of autonomy have not yet passed legislation in the Netherlands therefore, no further reductions have been made in this study at this moment.

The waiting time is also considered and the hourly costs relating to the waiting time of loading, unloading, waiting for freight, and general waiting time such as for locks or oncoming ships passing in narrow canals. This is shown in Table 8.

Total Cost per Year (Euro)	Conventional Operation	Remote Operation	Fully Autonomous Operation
Insurance	23.535	19.534	16.004
Repair & Maintenance	23.014	19.102	15.650
Interest	14.516	12.048	9.871
Port charges	27.638	22.940	18.794
Fuel	75.366	62.554	51.249
Other	11.988	9.950	8.152
Total Annual Costs	**561.018**	**465.645**	**381.492**
Savings		95.373	179.526

Table 7: Annual Operational Costs for M6 Container Vessel on Dutch Waterways. Source: Rijkswaterstaat (2023), Author

Industry	Vessel Class	Route	Hourly waiting costs (Euro)
Liquid Bulk	M6	Rhine	182.54
Dry Bulk	M6	Rhine	108.75
Containers	M6	Dutch hinterland	124.22

Table 8: Hourly Waiting Costs of an M6 Class Vessel per Route. Source: Rijkswaterstaat (2023), Author.

Smart shipping technology will reduce these waiting times as cargo management systems can integrate with port management systems for a more streamlined process, as found in interviews. Each of these factors makes up a direct cost benefit to the relevant stakeholders.

An estimation is made on the perceived cost reduction that the OCC and full autonomy will bring. According to Alias and Felde, 2022, the remotely monitored autonomous operation can yield a 17% cost reduction, and fully autonomous operation can yield a 32% cost reduction. These percentages have been factored into the cost breakdown.

The takings from this cost comparison are that the liquid bulk industry is estimated to achieve the highest economic benefit due to having the largest annual cost savings compared to dry bulk which is second and containers which are third. In terms of hourly waiting costs, liquid bulk also has the largest benefit with the reduction in costs with containers second and dry bulk third.

Liquid bulk is found to hold the highest total annual costs and therefore the highest economic benefit from AS due to the additional labor required and depreciation of the vessels. This is followed by dry bulk and third by containers due to over 6x more dry bulk goods being shipped out of North Sea Port than containers.

4.3.2 Improved efficiency

Smaller Vessels, Higher Frequencies Through literature with examples taken from central Europe, it was found that operating smaller vessels at higher frequencies reduces the costs of inland shipping and increases ship utilization. In an interview with the dry bulk terminal OVET, it was found that these types of operations are suitable only for outbound flows of their dry bulk goods due to the inbound flows being from short and deep-sea vessels where large capacities are prioritized. It is also found that operating multiple smaller vessels makes it more efficient for optimizing the draft of the vessel so it can pass through more routes at more times of the year due to the variation in water levels. Interviews state that this logistics finding is ideal for contract routing rather than the spot market where frequencies are high and constant each week.

In contrast, it has also been identified from interviews with each of the studied industry types that the high frequency of vessels opens possibilities for more late arrivals of ships at terminals which is not favored. OVET highlights that the throughput time of each vessel calling will increase with the addition of more vessels. It is quicker to moor, dock, unload, and load one large vessel than to split the cargo over multiple vessels and repeat this process. Also, DOW highlights that if the ships are propelled by conventional fossil fuel sources, then there is an increase in Co2 emissions per tonne per kilometer.

The result is that operating smaller vessels at higher frequencies will not be an ideal logistics solution for the adoption of AS in Zeeland as it is not favored and welcomed by the Zeeland terminals. Additionally, some routes served by North Sea Port are long distance which is more profitable to transport higher capacities.

Loading and Unloading It has been found through desk research that there are many limitations on the loading and unloading of vessels. Weather can act as a barrier to operations as highlighted by the dry bulk interviews. Some dry bulk cargoes such as grain and fertilizers cannot be loaded/unloaded in the rain and strong winds can blow dust into nearby residential areas located near the port such as Terneuzen. Strong winds coming in from the North Sea can also make it too dangerous to operate cranes and should therefore be considered as it increases the waiting time of the vessel.

Vessels arriving late are found to be the largest constraint on the ports in Zeeland. Assets are planned to a certain time for when the vessel arrives. If the vessel is late then more costs are incurred and a knock-on effect is caused by later arriving vessels waiting for a space to unload.

It is therefore found that the improved efficiency of AS is brought by the technologies that it offers, which are identified above. Improved navigation, continuous sailing, and the integration of cargo management systems with port management systems will shorten lead times and allow more trips to be carried out per year.

4.3.3 Investment

Infrastructure Throughout desk research, terminals that operate cargo from each of the three focused industries were asked about who should invest in the infrastructure to support AS technology. A mutual understanding was made between the dry bulk and container industry that both vessel operators and port authorities should collectively invest in infrastructures such as mooring and docking systems which require applications onboard and on the quay. This is due to the condition that long-term contracts with the customer can be achieved to secure these investments. Liquid bulk sees less benefit in this and does not plan to invest due to the industry already being well developed in the area and no cost benefit shown from their perspective. The initial investment costs of setting up the OCC, alongside the associated costs in maintaining it, must also be considered. It is estimated that the initial investment will be €1.9 million with an annual operating cost of €797,300 when accounting for operations with 90 vessels (Kretschmann et al., 2017). The OCC is expected to be set up in an area with good internet infrastructure and a stable electricity connection with the grid.

On board technology Each industry was also asked for their opinion on the trade-off between high investment costs in adopting autonomous technology and the perceived economic benefits found in the literature. All three industries agreed that it should be the vessel operators who should make this decision and that one party in Zeeland should adopt it first so that other industries can see how it works in practice. This company should serve frequent routes and have high operational costs and high capital due to economies of scale. In the case of Zeeland, companies such as Danser and Maaskade were named due to the size and stability of their fleet in the region and their high operational costs which are found above to involve mostly fuel and labor costs.

The acquisition costs of the fully adopted technologies where sailing, passing through locks and bridges, and fully autonomous mooring and docking are estimated to be around €1,000,000 if adopted this year with 10% of this cost additionally required for maintenance of the systems (Panteia, 2021). Depreciation of the current vessel is also accounted for in the investment costs as it found that vessel owners will prefer to upgrade their vessels rather than purchase new vessels with these technologies. A summary of the investment costs is shown in Tables 9, 10 and 11.

Investment costs (Euro)	Conventional Operational	Remote Operation	Fully Autonomous Operation
Depreciation of current vessel	152.138	126.275	103.454
New technology onboard	0	200.000	800.000
Maintenance of new Tech.	0	20.000	80.000
Total Investment Costs	**152.138**	**346.275**	**983.454**

Table 9: Total Investment Costs of AS Technologies on an M6 Liquid Bulk Vessel on the Rhine. Source: Panteia (2021), Author.

Investment costs (Euro)	Conventional Operational	Remote Operation	Fully Autonomous Operation
Depreciation of current vessel	42.766	35.496	29.081
New technology onboard	0	200.000	800.000
Maintenance of new Tech.	0	20.000	80.000
Total Investment Costs	**42.766**	**255.496**	**909.080**

Table 10: Total Investment Costs of AS Technologies on an M6 Dry Bulk Vessel on the Rhine. Source: Panteia (2021), Author.

Investment costs (Euro)	Conventional Operational	Remote Operation	Fully Autonomous Operation
Depreciation of current vessel	58.191	48.299	39.570
New technology onboard	0	200.000	800.000
Maintenance of new Tech.	0	20.000	80.000
Total Investment Costs	**58.191**	**268.299**	**919.570**

Table 11: Total Investment Costs of AS Technologies on an M6 Container Vessel on the Dutch Waterways. Source: Panteia (2021), Author

This summary was created by using the studied development paths from (Panteia, 2021) as a benchmark while comparing with the "Kostentool Binnenvart" (Rijkswaterstaat, 2023) and interview findings.

Development paths 1 and 2 were combined to create the investment costs for remotely monitored autonomous operations due to operations being controlled from the shore alongside the need for humans to assist with lock operations, which is supported by operations from SeaFar. Development path 3, where technology for autonomous mooring is incorporated, allows for full autonomy.

With such high investment costs, the trade-off between investment and perceived benefits is expected to be adopted as the return on investment can be made within a decade as shown in the cost savings section above.

Operators in Zeeland can benefit from the many forms of cost reduction but are limited to increasing efficiency due to limitations in the terminals and the inclination to adopt certain logistical methods from the relevant stakeholders. The economic benefits achieved by AS are something companies should incorporate in their strategies for the long term because adopting the required technologies involves high investment costs.

4.4 To which extent is human participation impacted by autonomous shipping in Zeeland?

4.4.1 Answer to shortage of skippers

Literature suggests that there is consensus that autonomous shipping will help alleviate the shortage of skippers (Nordahl et al., 2023; Pauwelyn & Turf, 2023). Indeed, one of the survey participants (i.e. Seafar, a teleoperation service provider) indicates the relevance of this aspect as he knows closely that fewer people are choosing the career of captain, making this shortage unavoidable in the upcoming future.

4.4.2 Crew reduction

The main focus of autonomous shipping is to reduce crew from vessels to reduce labor costs. Desk research supports that this is the largest benefit that smart shipping brings, however to what extent is this possible in Zeeland? Due to the same vessel type being a focus for each of the three routes in this research, the labor requirements onboard currently remain the same.

For continuous 24/7 operations of the IVa M6 Rhine-Herne Ship motor vessel of fewer than 86 meters in length, there are 4 crew currently required. This is made up of 2x skippers and 2x sailors (United Nations, 2004).

With the adoption of remote operations, crew levels onboard this vessel type will be reduced to 1x skipper during the piloting phase of new routes for the remote control center. Onboard crew levels will then be removed for sailing once the route is well into its operations and in the hands of the controller in a remote control center. Legislation from each participating country is required which creates a large barrier for the implementation of uncrewed operations.

Now that onboard has been considered there are also labor requirements on the shore for operating locks and movable bridges. In an interview with SeaFar, it was stated that although the vessel can operate fully remotely from the onshore center, there is still a person required to follow the vessel in a car to assist with guiding the vessel through locks and narrow movable bridges. There are mooring technologies available to perform this task but infrastructure and the trust in the technology by barge operators have not caught up with technology developers, resulting in an adoption gap between both parties.

For Route 1 from Terneuzen to Basel, there are 3x locks in the Netherlands and 10x locks south of Karlsruhe from which many are not automated and vary across the Netherlands, Germany, France, and Switzerland. Personnel are required to guide the ship through each lock resulting in a large reliance on human participation.

Route 2 from Vlissingen to Duisburg, includes only the 3x Dutch locks where personnel are needed. However, this route may be quicker to adopt as 2x of these locks are in Zeeland and all 3 in the Netherlands. Therefore, a regional or national approach to developing mooring technology infrastructures and legislation can be made to speed up the adoption rate of autonomous vessels along this route.

Route 3 from Vlissingen to Rotterdam can be approached in the same way. Along this route, there are 5x locks where 4x are within Zeeland so it is found that a Zeeland approach to developing smart shipping and mooring infrastructures can speed up the adoption rate in the region.

4.4.3 Vessel Ownership

Throughout further desk research, it is also made clear that most inland vessels, which currently operate in the Netherlands, are family-owned where the crew often live onboard the vessel. An interview with a Zeeland container terminal pointed out that the majority of vessels they load/unload are family-owned and operate on the spot market rather than contract routes, where routes depend on the market prices at that particular time. With the variation of routes and inconsistency of frequencies, it will be difficult for autonomous shipping to be adopted here. According to Panteia, 2021, 90% are family businesses or cooperatives in the dry bulk industry and 10% are owned by shipping companies. With this in mind, it is clear that the adoption of new vessel designs with the crew accommodation and sanitary facilities removed will become difficult if not unrealistic in Zeeland as these facilities are required by the owners/operators off duty as well.

4.5 Safety

The increase in safety that autonomous shipping brings is relative to human participation in the sense that the more humans are removed from operational processes, the safer they will be. Onboard the vessel, it is found that human error due to fatigue is the main cause of inland shipping accidents, therefore, transferring these tasks to remote operations will reduce risk in navigating the vessel. In the container industry, an increase in safety can be found in the loading and unloading of TEUs by removing the need for humans to manually lock containers onboard the vessel once lowered by the crane.

In contrast to this, it is also found that Zeeland terminals each want humans to operate the loading and unloading of the vessel. Interviews with dry bulk and container terminals highlight that there needs to be a level of responsibility when accidents occur and that somebody must be held liable. A particular focus is found in the liquid bulk sector where a strong stance is held on humans loading and unloading the vessel. When unloading vessels, the storage hold must be properly cleaned to remove any residue from the previously unloaded cargo so that no chemical reactions happen when loading the vessel. Pressures within hoses and pipes must also be monitored and controlled by a human as leaving these processes to robotics leaves nobody responsible or liable for accidents such as an explosion or oil leak for example. Insurances also permit that somebody is responsible for each aspect of the unloading/loading of vessels.

4.6 Remote Control Center

Throughout the collection of primary data, a common aspect found throughout all interviews is that humans will be in the loop to some degree. The first stage of smart shipping that is expected to be introduced in Zeeland, which each industry and technology developer is expecting, is remote-controlled operations with crew onboard, leading towards remote-controlled operations without crew onboard. Captain AI believes that remote control is the last stage of AS adoption and that there will always be human involvement in autonomous sailing. This stage is already in operation in Antwerp by SeaFar which operates all 3 industries that are focused in this paper and plans to extend operations to the Netherlands once legislation permits. A question was raised to SeaFar to discover the main criteria needed for building a remote control center and the findings are that it does not necessarily need to be in the port area. All that is required is a strong and consistent internet connection and a power supply. SeaFar are located in Antwerp so they can be close to their customers and make use of the passed legislation in Belgium of operating inland vessels remotely.

With the addition of a remote control center for inland shipping, there needs to be a supply of workers to carry out these tasks. Training programs will need to be implemented in the Netherlands to support the shift of skill requirements in this industry. Currently in SeaFar, remote control operators are monitoring 3 vessels at once with a deckhand following the ship in a car to assist with the locks. Employees work 8-hour shifts and operations are 16 hours a day from 06:00 to 22:00. Fatigue is reduced as controllers only work 8 hours rather than 14 hours. Besides that, each skipper is allowed to work onboard the vessel and the controller can disconnect from the job between shifts for full rest so fatigue is reduced significantly. During remote operations controllers can monitor and take over control of the vessel when needed with access to the ship's horn, secure phone systems to connect with any crew onboard, alarms on the vessel, and can use audio sensors to listen to the engine.

With technology constantly evolving on this hot topic, further improvement in cybersecurity is required. It is found that a lot of effort is going to be needed to secure safe internet usage via 5g. Control of the vessels needs to be completely secure as interference can lead to fatal and ecological disasters. A supply of personnel and systems to ensure this security will be needed.

Overall, human participation is expected to be reduced onboard the vessel but not removed, at least for the short term. The change of skills required for inland shipping in Zeeland is expected to shift towards a remote control center with new roles and training programs to be implemented and ideally requiring less people per ship. This change, will gradually help alleviate some of the current challenges in the sector, i.e. the shortage of captains and skippers.

5 Conclusions

Throughout this research, the objective is to find out how autonomous shipping can be applied to logistics chains and adopted by North Sea Port terminals in Zeeland. Using the information gathered from literature, interviews, and datasets it is now possible to answer how this technology can be adopted in the mentioned region.

By assessing each aspect of the theoretical framework in comparison to the information obtained from the technology experts and stakeholders, several drivers of adoption could be found. The proposed model for Zeeland and which largely builds on previously proposed models (Fonseca et al., 2021; Nordahl et al., 2023; Park et al., 2022) is shown in Figure 13.

The proposed adoption model takes into account the particularities of the context of Zeeland, and the extent to which the reviewed technologies are feasible, the economic benefits that could be achieved, and to which degree humans participate. The authors believe that, once all the barriers of each one of the drivers are satisfied, autonomous shipping adoption should be triggered. The authors also believe that this adoption is a process that will differ per inland shipping market segment and that would take no less than a decade to complete.

Relevant technologies are evaluated by experts in their respective fields and it is confirmed that multiple sensors and communication systems should be integrated to achieve maximum benefit and prove that autonomous shipping technology is safe and feasible in Zeeland. A strong internet network signal is required for the remote motoring and controlling of autonomous vessels, which currently is sometimes problematic in the proximity to the border with Belgium.

It is concluded that the container industry will find it easiest to adopt remote operations as much of the container flows from North Sea Port serve other Zeeland ports and Rotterdam therefore no network switching will be required. This finding matches the results of Nordahl et al., 2023 where short-sea shuttle-type ships at the national level are expected to be the first ones to adopt autonomous shipping. Based on

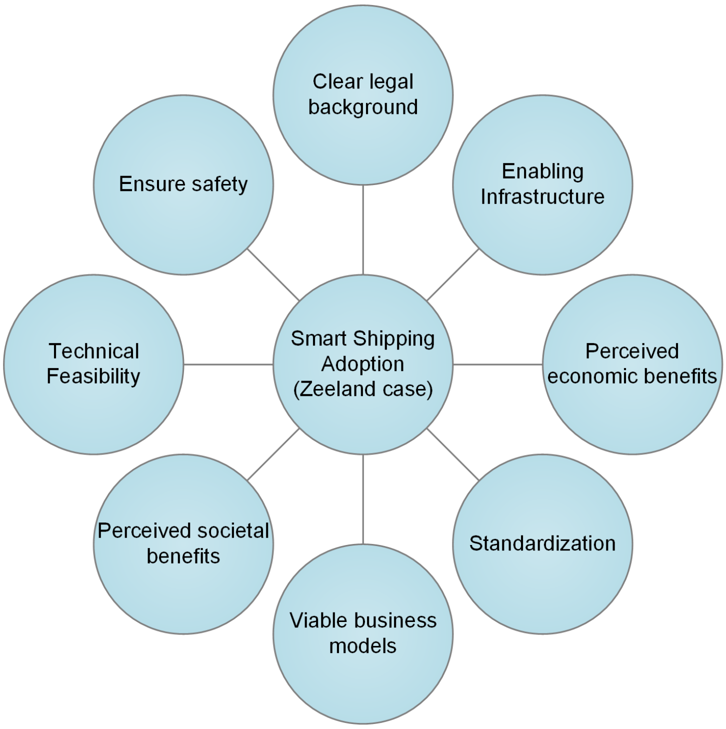

Figure 13: Proposed Adoption Model for Inland Autonomous Shipping in Zeeland. Source: Own Authors.

interview responses, it is expected that continuous flows, such as Rotterdam ↔ Zeeland or Antwerp ↔ Zeeland, will pose less complex scenarios for autonomous shipping to be demonstrated and proved useful. Based on responses, this adoption is more likely in container cargo due to more present standardization for loading and offloading operations.

In this study, two technological gaps are found regarding the adoption of smart shipping technology to logistics chains in Zeeland. First, technology developers are trying to push for full unmanned remote operations as the end goal, yet, terminals want there to be a human present and involved during this process so that liability can be held if accidents occur. Second, another gap between both parties is regarding the fuel source for the vessels. Developers still firmly believe that fossil fuels are the optimal source for autonomous shipping, but terminals are longing to make the transition to sustainable fuel sources to align with their sustainability goals. Fuel cells are found to be the optimal choice.

The breakdown of the associated costs of each industry type concerning their selected routes concludes that liquid bulk can expect the largest economic benefit when adopting smart shipping. Second is dry bulk and the third is containers, due to the requirements of each industry along with the frequency of routes from North Sea Port terminals to their destinations. Operating smaller vessels at high frequencies will likely not be favored by Zeeland terminals due to the shortcomings outweighing the benefits (i.e. increased traffic and increased mooring and off-mooring movements leading to delays). It can be confirmed that slow steaming is currently favored by stakeholders in Zeeland and is viable to incorporate inland goods flows to and from North Sea Port terminals to reduce fuel/power consumption.

As for onboard inland vessels, manning levels will be reduced to much fewer crew members onboard resulting in a shift in skills and roles towards a remote control center. This is the correct way forward to tackle the growing shortage of skippers in the industry nevertheless, training programs are required to educate employees on working with new technologies. Terminals will continue to require human participation during the unloading and loading phases to ensure safety, liability for accidents, and insurance reasons. New vessels designed with increased capacities by removing crew accommodation facilities seem to be difficult to adopt in Zeeland due to many vessel owners in the region living onboard the vessels (e.g. for dry bulk smaller ships).

For North Sea Port terminals to adopt smart shipping, a trade-off is expected to be made. Investment in this technology is expected to be high depending on the various levels of technology that are adopted. Investments need to be made secure by achieving long-term contracts with customers and making joint investments in port infrastructures however, the benefits through reduced labor and fuel consumption will ultimately be achieved. A mutual standpoint from Zeeland stakeholders is that shippers who operate on a large scale will adopt this technology first as a benchmark for others to follow. This is in line with the results of Panteia (2021), where the largest benefits, -and hence more urgency to adopt- are expected for larger tankers operating in continuous mode (i.e. 20-24 hours a day) and where market dynamics are stabilized via long term contracts.

Considering all the information provided in this research, it can be concluded that the container segment will likely be the first to adopt smart shipping technology in Zeeland due to regular goods flow and the readiness of the industry currently because many processes are standardized. A nationwide network is sufficient and the frequency of routes between Zeeland terminals and Rotterdam is constant. The second segment is expected to be liquid bulk but to a reduced degree of automation so that large economic benefits for the high volume of voyages are achieved but safety is sustained and compatible with terminals. By default, dry bulk will be the third to adopt as the industry holds medium frequencies and medium economic benefits to be achieved.

One large caveat that must be acknowledged after our conclusions are drawn, is the fact that most of our reasoning takes from current inland shipping market dynamics in Zeeland (which is also in line with most of the studies addressing the implication of smart shipping) and excludes the potential of road and rail movements to and from Zeeland that can shift into waterborne transport. This is for sure, a fundamental aspect to consider in future studies looking at the potential of this technology in this region.

6 Recommendations

For autonomous shipping technology to be adopted in Zeeland several recommendations can be gathered from this research.

The largest barrier to inland smart shipping in Zeeland is legislation and this is concluded based on both literature and interviews. The Dutch government alongside the neighboring countries of Germany and France may take inspiration from Belgian legislation and accelerate the approval and conditions fulfilments of the first stages of remote control with crew onboard. Doing so will allow terminals and inland vessel operators to begin considering inland smart shipping in their future development paths and can trigger new start-ups in the region that may offer cheaper alternatives to smart shipping technology.

Secondly, there should be improvements made by network providers and the EU to improve the quality and consistency of internet networks surrounding inland waterways so that remote control operations can take place. Poor internet signal is a large constraint found by SeaFar when remote operations began. Since each country operates separate network providers, the EU may decide on a strategy of subsidizing network companies to overlap in border areas or even create an EU-subsidised internet network privately for autonomous transportation.

Thirdly, the identified gap concerning the use of sustainable fuel sources between technology developers and Zeeland terminals should be shortened. Since it is found that technology developers are pushing for their autonomous shipping technologies to be adopted, they need to align themselves further with the goals of their customers. Sustainable fuel sources are unquestionably the future and developers may decide on incorporating fuel cell propulsion systems, along with their current offerings, to get their customers onboard.

With the conversion of responsibilities from onboard skippers to control center operators, the new skills necessary for these roles should start being incorporated now in maritime colleges and internship programs should also be created. The shortage of skippers is increasing, and it will take a few years to train operators to work with autonomous vessels. Therefore, there is an urgent need to prepare humans to carry out these tasks. Port staff will also require training to work alongside the new smart shipping technologies, systems, and maintenance procedures that are to come. Learning such skills will ensure an adequate supply of staff in Zeeland terminals.

Lastly, to kick-start the adoption of inland smart shipping in Zeeland, an early adopter is needed. As highlighted in an interview with Vlaeynatie, nobody wants to be the first to adopt and it is only logical that a company with high operational costs due to economies of scale and stable contract routes with high frequencies of vessels may be the first to make the change.

It was advisable that there should be a push by technology developers and incentives from the EU for pilot projects in the region in cooperation with these types of companies to kick-start the process.

From within the company, feasibility studies should be conducted to test the technical, economic, and human aspects of incorporating smart shipping in their operations. By analyzing their current routes, cargo types, and operational requirements as suitable use cases. They can identify the benefits, costs, and risks associated with adopting autonomous shipping technologies. In doing so, companies will then be prepared to adapt when legislation allows for it.

Answers	**Recommendations**	**Contributor**
Overcoming regulatory barriers that are currently blocking the adoption of inland autonomous shipping.	Approve legislation to allow remote control operations with crew onboard.	Dutch Government
A strong internet network signal is required for the remote motoring and controlling of autonomous vessels.	Improve internet infrastructures through a holistic sense between countries.	EU
Using sustainable fuel sources to speed up the adoption of terminals.	Push autonomous shipping technology with sustainable fuel sources to support.	Technology developers
Training programs are required to educate employees on working with new technologies.	Begin training individuals with the required skills to work in onshore centers as remote controllers. Also, terminal workers should be trained to work alongside the new autonomous technologies, systems, and maintenance that will become apparent in the future.	Educational bodies Terminals.
The container industry will be the first to adopt autonomous shipping technology in Zeeland due to the level of goods flows and the readiness of the industry currently because many processes are standardized.	Encourage large vessel companies to begin pilot projects with autonomous shipping technology adopted through incentives or reduced investment costs. Feasibility studies should be conducted by vessel operators, large companies in particular, by analyzing possible use cases for adopting smart shipping technologies so preparations are made for when legislation allows.	Technology developers Dutch Government. Vessel operators

Table 12: Summary: How can autonomous shipping be applied to logistics chains and adopted by North Sea Ports in Zeeland?

It can be seen below the proposed roadmap for adopting and implementing AS technology in Zeeland. Between now and 2025 (as shown in Figure 14), it is expected to be a push towards the Dutch government from vessel owners and technology developers to pass legislation on allowing the first level of remote shipping with crew onboard. If legislation is not passed before 2025, adoption will be delayed. The delay of adoption may continue to impact the bottom line of many technology developers and barge operators because smart shipping brings the opportunity to reduce labor and fuel costs alongside tackling the problem of skipper reduction. Aside from legislation, work should be done now to begin training employees who will carry out these new roles as remote controllers. Courses should be implemented by maritime educational facilities so that when adoption moves through each stage, a supply of workers will be there as training will take time.

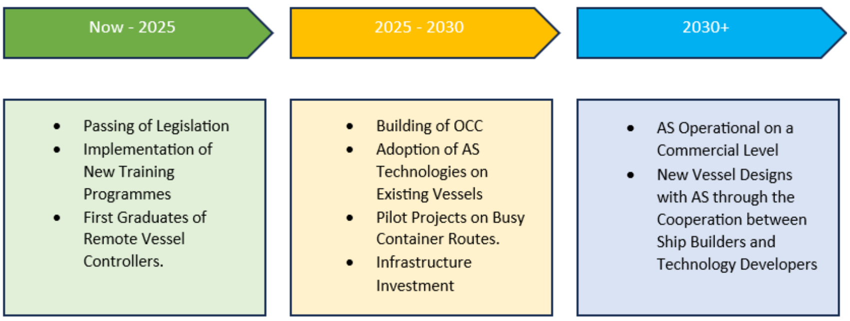

Figure 14: Summary of Roadmap for AS Adoption in Zeeland. Source: Own Authors.

From 2025 to 2030, a remote control center may ideally be enabled for Zeeland operations. At this stage, smart shipping technologies will begin to be incorporated into existing barges with the addition of sensors and AI networks so that data can be collected and processed onboard the vessel and transferred to a remote control center. This will be possible due to autonomous shipping technologies becoming economically profitable as with the passed legislation. It is also expected that many startup companies will offer cheaper alternatives of software and sensors. Busy container routes, such as route 3 in this study, should run pilot projects with remote-controlled vessels with a skipper onboard to intervene when necessary. This is expected to be introduced through a collaboration between North Sea Port terminals and barge operators so both can benefit as a result. Infrastructures will need to be upgraded on Dutch inland waterways by government bodies so that autonomous shipping technologies can communicate with the riverbanks and islands. Investment in infrastructures will benefit the local economy, reduce emissions, and increase safety which each will help drive public investments due to a shared benefit being achieved. Once container routes are in autonomous operation, a focus should then be moved to liquid and dry bulk.

In this scenario, autonomous shipping is expected to be operational in Zeeland on a commercial level from 2030 on. From this period onwards, there may be a shift towards unmanned sailing on selected routes. However, a vessel operator will have to be on board the vessel in the port areas unless terminals become more open to full autonomy. It is expected that North Sea Port and private terminal operators will begin to change their views on manning levels, around this period, due to the success of pilot projects and adoptions that have happened so far. After 2030, there will be a rollout of new vessel designs with incorporated autonomous shipping software and sensors onboard. Shipbuilders such as Damen and Kongsberg, who are present in the region, will likely kickstart this rollout and cooperate with technology developers so that the state-of-the-art is applied onboard their vessels. It is a possibility that new designs will be more aerodynamic and involve fuel cell technology as a means of propulsion. At this stage, skipper levels will have reduced significantly. Therefore, the removal of the bridge and crew accommodations may be possible for a small number of companies depending on the ownership of the vessels.

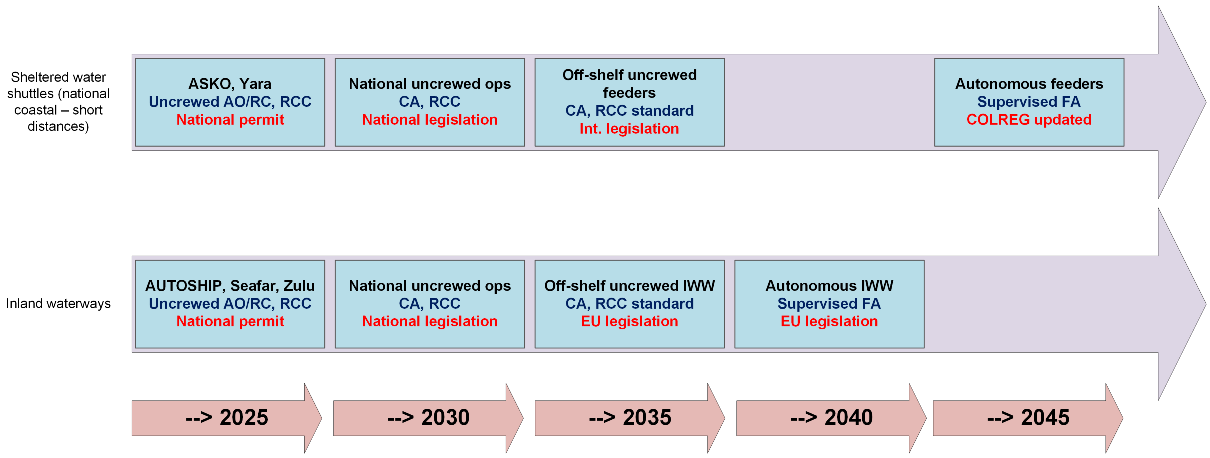

Figure 15: Taken from Nordahl et al., 2023 Note: Short-sea and Deep-sea excluded

The proposed roadmap in this study is contrasted with the high-level realization roadmap produced in the AUTOSHIP project (Nordahl et al., 2023). For both, short-sea national short-distance services and inland waterways, working use cases are either functioning or expected in operation in the short term (i.e. Yara Birkeland, ASKO ferries, Seafar, Zulu). They expect these modes to be the first ones to attain *uncrewed automatic operation* and *remote control operations* under issued *national permits*. *Constrained autonomy*, i.e. uncrewed operation with RCC personnel, is to be achieved at the end of 2030 under *national legislation*. *Full autonomy* will be realized no earlier than 2040 under *EU legislation*. The major aspects of these two roadmaps coincide, mostly on the type of transportation modes that will first adopt smart shipping. The main differences lie in the expected time for regulations to be accepted, which in the case of Zeeland is expected to occur earlier due to the mentioned pressure by stakeholders in the Netherlands. This can be explained by the fact that the AUTOSHIP project has a much wider scope that the one selected in our study.

7 Final Remarks

From comparing empirical findings with what was presented by existing literature, there are many similarities and differences present. From a technological perspective, the use of satellites to assist in data transfer will be required as a backup for when internet network access cuts out. Satellites can communicate from S2I (Martelli et al., 2021) so that the remote control center can connect uninterruptedly with the vessel. The use of RADAR, LIDAR, and visual sensors will all become apparent as are already implemented in operations in Belgium (SEAFAR, 2022).

Operating smaller vessels at higher frequencies is found to be more efficient for operations in the German Rhine as it increases ship utilization in a theoretical sense (Alias & Felde, 2022) but it is not favored by Zeeland terminals as it will take longer times for mooring/unmooring potentially leading to an increase in the frequency of late arrivals.

Slow steaming has been proven to reduce fuel costs theoretically (Burmeister et al., 2014) and empirically this is also the perception of the stakeholders by reducing the level of fuel/power consumption.

Lastly, the end goal of smart shipping in theory is full unmanned autonomy (Ringbom, 2019). In contrast, the empirical interviews with Zeeland terminals made clear that a human involved in each process is preferred for responsibility and liability. While the adoption of this new technology by vessel operators advances, terminals may change their views in coming years when the level of safety required is met, insurance policies are reassessed, and legalities are made about the liability of accidents. Increased environmental and cost benefits will also influence the views of terminals to be more in favor of unmanned vessel operations.

For future research, it is suggested that each new technology be considered in its specificities and investigated for adoption in Zeeland. Autonomous shipping technologies are constantly being developed with new additions to the market and are sure to continue developing in the future.

Acknowledgements

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A Data Condensation of the Interviews Conducted through Coding

Captain AI- Technology developer - Color red
SeaFar - Ship Teleoperation services - Color orange
OVET - Terminal - Color violet
DOW - Large scale shipper - Color blue
Vlaeynatie - Third-party logistics - Color dark gray

Topic	Quotes	Finding
5g Connectivity	"The ship should always be able to rescue itself if the connection is lost so there should be a combination of 5g and internet to satellites so a combination of both is ideal." "The quality of the data network (4/5g) is very bad near the border of Belgium therefore if vessels aren't able to connect because of this reason then it is an issue in our region."	The signal is weak at border areas between countries. There cannot be a sole reliance on 5g networks.
Data Analysis	"Onboard you have your computers, you have your software running there that are connected to both sensors and steering of the vessel. IoT is applicable yes." "This device will be leveraged to process AIS or Radar data for sensor fusion. Other sensors' data is processed onboard as well to be formatted before being communicated to a cloud platform. From there it's sent to the control dashboards requesting that information."	IoT analyses sensors onboard the ship and communicates via a cloud platform to the controller's dashboard. Uses sensors as input and steering as output.
Satellites	"It will be the best way helpful in the full stack of autonomy to have a continuous connection with your ship but in the end, the ship should be able to man itself when the connection is lost so there should always be developments there." "Yes, so cameras, RADAR, GPS, GNSS, AIS"	LEO & GNSS should be used as a backup for when the internet network signal cuts out.
Sensors	"That's how autonomy works so your sensors feed directly and data is processed and then something is done with that processed data." "We use a set of IP cameras that offer hi-res real-time Video feed, night vision, and that are equipped with robust casing." "When entering there are some dead angles and having info from the LIDAR can tell you how far you are from the lock walls."	A combination of sensors should be used. LIDAR is most useful in the locks. IP cameras offer a high-resolution, real-time video feed with night vision, robustness, and low costs.
Mapping & GPS	"The automatic waypoint following system we include what we call geo-fences. When the water truck reaches a geo-fence it stops such a bridge and it waits for its assignment."	Geofencing is used to set boundaries for AS.

Automated Mooring & Docking	"If legislation allows the transportation of dangerous cargo autonomously with no onboard supervision then that is the biggest risk/concern I have. I believe the sailing can be autonomous but what if something happens with the hoses such as a gasket breaking for example, who will be liable for this."	Not welcomed by Zeeland terminals as they want humans involved in the process for responsibility and liability.
Navigational Systems	"Track pilot, automatic report following and automatic identification target system are most important."	Use of track pilot, automatic report following, and automatic identification target systems can be used.
Propulsion	"I don't have much of an opinion on that, in regards to autonomy as long it can interchange with the motors, steering and keep out of trouble then it doesn't matter if its hydrogen or batteries." "I think fossil fuel is still better because it doesn't require as much space. I spoke with other professionals and they outlined that batteries could be the size of a 20ft container so takes up a lot of vessel space." "In the next 25 years sustainability will be a large challenge therefore as soon as a connection where there is a benefit to your emissions then adoption will speed up." "It's also about sustainability and safety."	A gap was identified between tech developers and Zeeland industries where developers believe fossil fuels are going to be continuously used and industries want to make the move toward sustainable fuels.
Legislation	"We need European regulations rather than dealing with 5 different permits in Belgium, the Rijkswaterstaat in the Netherlands, and the Rhine Commission. A combined set of regulations is needed." "The problem is that the rules are not changing fast enough so without changing the regulations then there will be no adoption of AS because it's currently not allowed."	Acts as the largest barrier to adopt inland AS in the Netherlands.
Integration of Management Systems	"When it is a fixed set-up and everything is covered in contracts then why not? This level of data sharing can add additional efficiency." "The more transparency there is the better it is for both parties as you know what you can expect and there are no surprises."	Cargo management systems onboard the vessel can integrate with port management systems for a more streamlined process.

Smaller Vessels, Higher Frequencies	"For outbound flows, it can work but for inbound, the shipments we get are usually from North and South America therefore the vessel size is best when as big as possible." "We are facing problems with the barges where changes in water levels can limit how much we can load the barges therefore it could be better to load 2 barges with 2000 tonnes rather than 1 barge with 4000 tonnes which could risk running aground." "It is easier for us to load 1 ship with 4000 tonnes as once we start loading we can just load it directly but with more ships at fewer capacities there runs the risk of one of them not arriving on time along with mooring and docking of each ship increasing the overall time." "The impact on emission should also be considered because if you ship smaller quantities the emission per metric tonne will be higher."	Suitable only for outbound flows of dry bulk. Useful for optimizing the draft of the vessel so more routes can be carried out at shallower water levels. This opens possibilities for more late arrivals when calling at ports. Faster to unload/load one large vessel than multiple small vessels. Co2 emissions will increase with more fossil-fuelled vessels.
Unloading & Loading	"We cannot load during rain for products such as cement and fertilizers, this is a big problem. The wind is sometimes a problem with dusty products where we sometimes need to stop." "Runs the risk of one of them not arriving on time along with mooring and docking of each ship increasing the overall time."	Limitations include weather with wind and rain limiting dry bulk operations and late arrivals creating a knock-on effect on later arriving vessels.
Investment	"It should be a shared investment. Shipping goods from A to B involves both parties and should collectively pay for this investment. Often when investing for things like that we will ask for a certain level of commitment from our customer so we can secure that investment." "I think it is a 1+1=3 operation. When it is open to everybody then arrangements can be made as we need each other and cooperation for the adoption of AS to work. The solution cannot be created by one party alone, so it must be from both sides." "If the current operations are giving me a net profit of millions as a terminal and if the owner wants to shift to an autonomous terminal then I will still make my profit, why invest."	Dry bulk and container industries believe a shared investment should be made for AS infrastructures in ports if long-term contacts can be held. Liquid bulk doesn't see much benefit in this.
High Investment Costs vs Economic Benefits	"In the ideal world, the vessel operators should make this investment first." "The risk is fully on the vessel owners." "Companies who group vessels or have their own stable fleet of vessels should make this move first." "I think there needs to be one barge party that is willing to go for it and has a continuous flow from an origin to a destination"	Barge operators should make this decision. One party should adopt first for the rest to follow.

Remote Control Operations from an OCC	"At the moment we have a deckhand to follow the ship with a car as there is nobody in the locks to moor the vessel." "Anywhere with a good connection and power supply." "To reduce fatigue and increase safety we work 8-hour shifts and operate as a centre 16 hours a day and our workers can go home after 8 hours and disconnect and relax. The shifts are 06:00 to 14:00 and 14:00 to 22:00."	Vessels can operate fully remotely from an OCC but a human is required to follow the vessel to assist with locks. An OCC relies on a strong internet signal and a power supply. Operators work 2x 8-hour shifts from 06:00 to 22:00 to reduce fatigue.
Ownership of vessels	"A lot are family owned who are mostly on the spot market."	Most vessels are family-owned and operate on the spot market.
Safety	"If legislation allows the transportation of dangerous cargo autonomously with no onboard supervision then that is the biggest risk/concern I have. I believe the sailing can be autonomous but what if something happens with the hoses such as a gasket breaking for example, who will be liable for this." "We would like to have somebody in person loading and unloading the vessel operating the hoses and pumps so that responsibility is made." "I know from my own experience that with containers there are responsibilities of locking the containers and securing them to the ship by the crew, which is something that can be susceptible to human error if not done correctly."	Safety can be improved by reducing manning levels onboard, but terminals want humans to be in control of the unloading & loading. Containers can be safely loaded without humans.
The end goal of AS	"We foresee that in the future ships will be able to sail autonomously from A to B but always will have humans in the loop as in remote control centers/remote monitoring centers like mission control. That's the level we expect to be the final level as well." "I think it will be containers that will be first to adopt where there is a continuous flow."	Remote operations without crew onboard. Containers will be adopted first.

Table 13: Interviews coding

B Interview transcripts

B.1 Captain AI Transcript

Date- 08/06/2023 18:00
Via- Phone call
Company- Captain AI
Position- Co-Founder and CEO
Purpose of the interview- To help with answering the question: "How can autonomous shipping technology be applied to the logistics domain in Zeeland?" Permission is given to record.

1. What does your company primarily focus on, what is your area of operations? Our area of operations for Captain AI is developing software to make autonomous shipping possible.
2. Throughout literature I have discovered that autonomy is looked at through many different levels

relating to human involvement, are there any different levels you can define, what are the different levels according to your knowledge? We foresee that in the future that ships will be able to sail autonomously from A to B but always will have humans in the loop as in remote control centres/remote monitoring centres like mission control. That's the level we expect to be the final level as well.

3. There are many navigational systems that skippers use today, which navigational systems do you feel will be most relied upon by autonomous shipping to navigate Dutch inland waterways safely? It's a combination of centres and charts so of course GPS, RADAR, cameras, maps and AIS. Many kinds of inputs will be needed for navigating safely on the waters.

4. To which extent do you feel RADAR should be relied upon, can it be solely relied upon, or should it work in tandem with everything else such as cameras, LIDAR. . . etc? We foresee a combination of centres indeed because you cannot rely on one centre alone so it will be a combination of RADAR and camera mainly. All sources can add to situational awareness.

5. Alongside the other centres mentioned, are there any sensors that you rely upon? Yes, so cameras, RADAR, GPS, GNSS, AIS. . . that's about it.

6. From your experience as a technology developer can you comment on the gap between the pushing of new technologies and the adoption by barge operators and ports? Do you feel that there is a gap and to what extent? The roadmap towards autonomy is to process warning systems onboard, autopilot to have more control, more like electric cruise control and then later all the centres and all the software will be added in one stack which will become the autonomous stack. In the first development now we have for instance with the inland navigation company called Periskal perhaps you have seen on our website we just released that news a few weeks ago, the collaboration there where first used are RADAR tracker and the detection model for collision avoidance.

7. Do you feel that technology implementation is limited due to port infrastructure at the moment? No, it is all about port infrastructure, but the problem is that the rules are not changing fast enough so without changing the regulations then there will be no adoption of AS because it's currently not allowed.

8. Isn't there a lot of investment and operating costs involved with that too? Well, if the business case is there then that's no problem. If you can sail autonomously then you don't have the cost of personnel so then it doesn't matter how high the costs are, it's the return on investment that's more important and beneficial in the long term.

9. Are there any technologies you feel won't be initially adopted by inland shipping operators due to the high investment costs? It goes back to the roadmap, first, what can be adopted now within the rules and then later the rules are changed so then it opens up to the adoption of technologies.

10. Throughout the literature it was found that an Onshore Control Centre seems to be a middle step towards autonomy, do you feel that using an OCC is optimal as a middle step? What are your critical thoughts on this? I don't see it as a middle step, I cannot foresee it as an area where there will not be a human in the loop in the end to oversee the vessels. You have to know where it is and those kind of things. You need to get information, there's plenty of things still to be done on the ship as well besides sailing from A to B. For me it's not a middle step, it's the end goal.

11. There are of course lots of regulations about this too, regulations at the moment say that there needs to be human involvement do you agree? Yes

12. How can cyber security risks be effectively managed and mitigated in the context of AS? It's no different than how it's currently managed on vessels. If anything, it will be safer because there's no human onboard that can interfere with the hardware. It's always a question I get for example the ships from Maersk were hacked because they were still running on Windows XP, that's a bigger issue but for the foreseeable future it's something I always answer that I don't see any different than it is now.

13. We mentioned there at the start about satellites for navigation, I have also found a lot about the use of satellites throughout literature such as GNSS and LEO satellites. Do you think AS will be more

dependent on both of these types of one of them? Which satellites will be more effective? With Starlink and other players coming into the field, of course, it makes the continuous connection with the ship possible inland or on the ocean so that will be the best way helpful in the full stack of autonomy to have a continuous connection with your ship but in the end, the ship should be able to man itself when the connection is lost so there should always be developments there.

14. Once data from the vessels are transferred it then needs to be analysed somehow, which type of technology is best for analysing the data? We don't like the term remote control centre because it's not like somebody just steering the vessel remotely it's more like a mission control where your just overlook and monitor the ship or give it a new mission but not steering it so the data is all processed onboard because that's how autonomy works so your sensors feed directly and data is processed and then something is done with that processed data. The input you get from the sensors, you are steering the vessel as an output therefore there is no remote control or steering control necessary for intervention there.

15. Do you feel that machine-type communication could be used for this? Literature suggests that Internet of Things is a type of AI that is applicable here, do you agree? Onboard you have your computers, you have your software running there that are connected to both sensors and steering of the vessel and some protocols can be used. Nothing special really, there is no term for this but IoT is applicable yes.

16. Literature suggests that the use of Wifi and 4/5g is something that may be used for connectivity in highly dense areas such as ports, do you feel that the use of satellites in this area is more apparent or the use of wifi or 4/5g for accurate connectivity? It's hard to know, we can see that Starlink can give better performance than some 5g networks but it's all about price so if it's cheaper to connect 5g then that will be the choice than to use satellite.

17. What are the shortcomings of using 5g, literature suggests that a lot of the trust and responsibility is being put towards the particular network provider, on the other hand, isn't that a risk or do you feel this method is reliable enough? Well again, the ship should always be able to rescue itself if the connection is lost so there should be a combination of 5g and internet to satellites so a combination of both is ideal.

18. Is there a particular type of power source that you feel should be considered in the future of autonomous inland shipping? A comparison was made in literature resulting in fuel cells being the optimal solution but do you feel that a combination of electricity & batteries with fuel cells is better? What are your thoughts on that? I don't have much of an opinion on that, in regard to autonomy as long it can interchange with the motors, steering and keep out of trouble then it doesn't matter if it's hydrogen or batteries. Batteries are much easier to control so that would be preferred but I don't see that happening any time soon.

19. Can you see any new technologies or innovations soon that you can talk about? We are at the forefront of that, together with AI we can now do detection with RADAR and cameras so there's much more we can do now than a few years ago. I think now with Chat GPT kind of applications we will see a lot more in that space in the coming years to make it safer and easier for vessels to operate.

20. In regards to the mission control centre we discussed earlier, I noticed that it's already being carried out in Antwerp by SeaFar. What timeframe do you think this will start being conducted in the Netherlands? Within the next 5 or 10 years? Its difficult because 5 years ago we thought that by now it would be accepted in the Netherlands as well but we are behind so that's a big shame because that will be a big barge opportunity there and has allowed SeaFar to grow, but regulations have the main role in this therefore I can not say that in 5 years it will be there because I said that 5 years ago. I think we are heading in that direction, but nobody is in a hurry except startups like us who want to see the world change.

21. Lastly, do you have any additional remarks, conclusions or questions that you would like to share? No, I think that is everything.

B.2 SeaFar Transcript

Date- 22/06/2023 10:30
Via- Teams
Company- SeaFar
Position- Traffic Controller
Help is also given by a SeaFar IT Engineer focused on AI computer vision.
Purpose of the interview- To investigate which technologies apply to inland autonomous shipping and are currently being used today. Permission is given to record.

1. What is your title and function within the organization? I am a traffic controller, some of our barges are semi-autonomous so once they are set on track-pilot they can follow the waypoint on their own so I'm just there to speed them up or stop them to avoid any situations. If we need to maneuver, we give the role to the captain onboard.

2. What does your organization primarily focus on? We are developing the technology to make inland barges remotely operatable. In the future we want them to be fully autonomous but there's a lot of work to do so now we focus on remotely operating the inland barges.

3. What regions does SEAFAR operate in? Are there plans for expansion? Right now, we mainly operate in Flanders Belgium but in the future, we aim to operate in the south of Belgium but there are different permits needed. We just applied for a permit in the Netherlands and we are currently speaking to the Rhine committee to operate in the Rhine so that we can operate in Germany and France as well.

4. In terms of infrastructure, what specific upgrades or modifications are necessary for ports to accommodate autonomous vessels? Automated mooring systems will be in the future. Right now there is no accommodation for this, at the moment we have a deckhand to follow the ship with a car as there is nobody in the locks to moor the vessel. There is also a need for 5g as we currently use 4g to connect and 5g will be better.

5. What are the main challenges to overcome for autonomous shipping to be introduced? We need a clear legal background because now we work with permits that we have for each vessel on the determined route for specific voyages so there needs to be a more open mind from authorities for adoption to work. We spend a lot of time writing our permits as each region in Belgium: Flanders, Brussels, and Wallonia have 3 different permits, port of Antwerp is another authority where there aren't permits but we have to make tests and there is the Scheldt when we pass a certain buoy it is not the Flemish waterway it is the GNA so different requirements again. In Belgium, we are busy with 5 different regulators. Another challenge is the coverage of the 4G network.

6. What are the main technologies SEAFAR uses to operate the vessels? Which sensors does SEAFAR use? We use everything that can be found onboard. LIDARS, RADAR, GPS, synchro sounders and anemometers. We don't use satellites ourselves just 4g. our cameras are already being used to detect other vessels.

7. Once data from the vessel is transferred it then needs to be analyzed, how do you feel about AI and the use of Machine Type Communication carrying out this task? What are the advantages and disadvantages of this? How is the data stored? The data acquired from multiple sensors are processed differently and AI (Machine Learning) plays a crucial part in multiple parts of our data analysis. The image processing is done on the Edge using a specialized SoC to accelerate the Computer vision application. This device will be leveraged to process AIS or Radar data for sensor fusion. Other sensors' data is processed onboard as well to be formatted before being communicated to a cloud platform. From there it's sent to the control dashboards requesting that information. This whole pipeline runs without a human in the loop.

8. There are many navigational systems that skippers use today, which navigational systems do you feel will be most relied upon by AS to navigate inland waterways safely? Track pilot, automatic report following, and automatic identification target system are most important.

9. Literature suggests that the currently available RADAR systems are sufficient for AS, how do you feel about this statement? Is wave or pulse RADAR more suitable? To what extent do you feel RADAR should be relied upon? Can it be solely relied on or should it work in tandem with other navigational systems? The RADAR is still reliable. Image data has its disadvantages. As an example, it is difficult to analyze images during nighttime or in bad weather. RADAR offers a great opportunity to apply sensor fusion with image data to have richer input data.

10. To what extent can LIDAR benefit AS navigation? What are the benefits and shortcomings of adopting LIDAR for inland waterway navigation? We use it for close distances such as entering the lock. When entering there are some dead angles and having info from the LIDAR can tell you how far you are from the lock walls.

11. Aside from detection ranging, which other technologies do you believe assist the navigation of autonomous vessels? Which types of cameras are best suited for inland AS? The best option would be Stereo Vision Cameras. They integrate hi-res camera sensors plus infrared sensors for distance measurement. This allows localizing of objects in the image and estimates their distance to the vessel, hence it offers 3D vision capabilities. These types of cameras can present inconveniences such as price and robustness against external factors. At Seafar we use a set of IP cameras that offer hi-res real-time Video feed, and night vision and that are equipped with robust casing. We use 2D object detection techniques based on CNN to localize objects in the image and apply sensor-fusion with AIS - Radar in the future- to obtain that extra dimension.

12. Which power source/fuel do you feel is most beneficial for autonomous inland vessels? To be honest, for AS it doesn't matter if it's fossil or electric. I think fossil fuel is still better because it doesn't require as much space. I spoke with other professionals and they outlined that batteries could be the size of a 20ft container so take up a lot of vessel space.

13. Can you see any new technologies or innovations being created soon that you may consider using that you can talk about? Computer Vision using Image data is important for AS. It has the role of replacing the Captain's vision, it can help 'detect' objects of different sizes, especially the smaller objects or people in the waterways. Plus, state-of-the-art AI techniques are more developed in image processing than Radar processing.

14. To what extent have you noticed goods flows shifting from road transport to inland water transportation? We don't have much of a vision on road transport but some of our projects such as "water trucks" are replacing trucks carrying polluted soil with vessels therefore if that wasn't done then there would be many more trucks. But from flow itself, I don't have much experience with it.

15. Throughout literature, autonomy is looked at through many different levels relating to human involvement. How does SEAFAR define the different levels? We don't define them we just follow literature such as Plantina, I think it's called. We are currently aiming at the level of partial automation.

16. What would you say are the main benefits to logistics of using autonomous shipping? Today there is a lack of skippers/captains. We are asked for help a lot due to the shortage of captains. We hope that our remote shipping solution will help relieve these pressures. Right now nobody wants to become a captain because you need to leave your home over a week which isn't favoured by many people

17. Do you tackle this by operating multiple ships per controller? For the pilot project with water trucks, we have 3 unmanned vessels except the deckhand following in their car to help with the locks. With an automatic waypoint following system, we can control 3 vessels with one captain and one traffic controller. The ratio is therefore reduced. In the automatic waypoint following system, we include what we call geo fences. When the water truck reaches a geo-fence it stops such a bridge and waits for its assignment.

18. Tell me about your thoughts on remote-controlled vessels operated from a shore control center. What benefits does this bring to operations in the port and while sailing? When using computers and technology we are creating safety because when AI is detecting other barges it increases situational awareness. We are building on this to try and detect kayaks and other small objects. In the control

centre, we work 8-hour shifts whereas onboard the captains are allowed to work up to 14-hour shifts. To reduce fatigue and increase safety we work 8-hour shifts and operate as a center 16 hours a day and our workers can go home after 8 hours and disconnect & relax. The shifts are 06:00 to 14:00 and 14:00 to 22:00.

19. What are the main challenges when controlling inland vessels remotely? What are the main navigational barriers? Loss of connection sometimes happens due to a weakness in the network. When we use a new route with a barge we keep the captain onboard as we don't know how the connection will be. AI takes a lot of time to develop and we have to teach the AI what the object looks like such as kayaks or swimmers in the water. We first need to see these things so we can input them into the AI.

20. In your opinion, what location do you feel is ideal for building a shore control center? For example: in the port, in the city, along the waterway? Based on what drivers? What infrastructures does a shore control center rely on? Anywhere with a good connection and power supply. Port is not necessary but we are located in Antwerp as there are a lot of companies besides us so we can be close to our customers.

21. What do you think governmental bodies and waterway managers need to do most to facilitate inland autonomous shipping in general? We need European regulations rather than dealing with 5 different permits in Belgium, the Rijkswaterstaat in the Netherlands, and the Rhine Commission. A combined set of regulations is needed.

22. What is the main cargo type your controlled vessels operate with? Liquid bulk, Dry bulk, Containers? Where does most of this cargo go? What are the main industries you operate for? We carry a bit of everything at the moment. We carry dangerous goods such as acid, polluted soil, and containers. We cover all three segments dry bulk, liquid bulk, and containers.

23. Do you think remote vessel operations are more beneficial for short or long-distance routes? Currently, we are trying to make it attractive to both, it is beneficial for both as skippers operate long and short differences and there is a benefit there.

24. To what extent is navigational safety ensured using remote vessel operations? We see the station control in the shore control center as part of the ship. We try to integrate as many controls as we can that the captain would see onboard. It is safer remotely than onboard. We can listen to the engine and trigger an alarm onboard to wake up the crew. We have a backup power supply at the station. We have the portable phones that the police use. In my opinion, it is as safe if not more than onboard the vessel.

B.3 OVET Transcript

Date- 16/06/2023 18:00
Via- Teams
Company- OVET
Position- Commercial Manager
Purpose of the interview- To find qualitative data about the adoption of autonomous shipping in the dry bulk industry. Permission is given to record.

1. What line of work does your company do? We are a dry bulk terminal located in the ports of Vlissingen and Terneuzen in Zeeland. We operate mostly with the black dry bulk products such as coal but we also are diversifying into fertilizers and other cargo due to the use of coal being reduced. We also work with sea ships who want to go to Ghent for example and they have too much draft so we empty one or two hulls for the ship so that they can sail there. That is our main focus.

2. Do you also work with other countries nearby such as Germany or France, or are all of your operations in Zeeland and Belgium? All our operations are in Zeeland, we are not the owner of the material we are just the logistics service provider. We could ship our cranes to other locations in Europe but as you can imagine it is expensive to bring our crane to another location in Europe and there are other companies there that can do that instead.

3. Can you identify some of the main costs involved with loading and unloading the vessels? The crane and the crane operator are the main costs along with storage costs in the yard. We can load from the quayside and move directly to our stock, or we can unload the bigger ship and reload it into a barge. There are also overhead costs but the crane is the most expensive part of the handling.

4. Could you identify any main limitations when it comes to loading/unloading vessels? We cannot load during rain for products such as cement and fertilizers, this is a big problem. We store our main products outside and they can be loaded with rain. The wind is sometimes a problem with dusty products and we sometimes need to stop, especially in Terneuzen where there are a lot of residential areas nearby and the dust is usually black. Besides that, we don't face problems with labor as we are in a location with lots of labor availability and we have a very loyal team e.g. only 2 people left the company in the past 5 years so we are good to our people and we trust they will be good for us. We like to retain our staff.

5. Throughout the literature, it was found that AS brings a possible business case for using smaller vessels at higher frequencies to maximize ship utilization. As a dry bulk terminal is this something you would like to see an increase in or would you prefer to work with larger vessels that may come less frequently? For outbound flows, it can work but for inbound, the shipments we get are usually from North and South America therefore the vessel size is best when as big as possible. When the destination each week is around 3000 tonnes for example then a discussion can be made if we will go by train, truck or barge. We are facing problems with the barges where changes in water levels can limit how much we can load the barges therefore it could be better to load 2 barges with 2000 tonnes rather than 1 barge with 4000 tonnes which could risk running aground. On the other hand, it is easier for us to load 1 ship with 4000 tonnes as once we start loading we can just load it directly but with more ships at fewer capacities, there runs the risk of one of them not arriving on time along with mooring and docking of each ship increasing the overall time.

6. To what extent do you feel terminal and barge operators will have to train crews to work with automation and how will these new required skills be adopted by the current labor? The most important part for a barge or a ship is that they arrive at the agreed time as we plan our capacities for that time. We only have a limited amount of storage and crane capacities therefore if a ship is late, it has a roll-on effect on everybody else. When on time the ship is cleared and cleaned according to plan.

7. In the literature, it is found that the move towards AS and automation is found to increase safety levels due to the reduction of human error leading to accidents. Which elements of your business do you feel the increased safety will benefit most? The only time we are working with the ship's crew and skipper is when they are docking to the quayside. I know from my own experience that with containers there are responsibilities of locking the containers and securing them to the ship by the crew, which is something that can be susceptible to human error if not done correctly.

8. Throughout the literature, autonomous shipping systems can integrate with cargo management systems in the port in the future. This will bring a need for transparency and cooperation between ports and inland vessel operators. Is this something that your dry bulk terminal is open to or do feel that this level of data sharing has its flaws? For us it's not a problem as we are not the owner of the cargo but our customer must be open to doing it (data sharing). The more transparency there is the better it is for both parties as you know what you can expect and there are no surprises. The customer is the person who should make that decision.

9. In the future, it is expected that there will be automated mooring and docking systems onboard and/or on the quay. Do you think that is something that the ports should invest in or the barge operators? I think it is a 1+1=3 operation. When it is open to everybody then arrangements can be made as we need each other and cooperation for the adoption of AS to work. The solution cannot be created by one party alone, so it must be from both sides.

10. Throughout my desk research, I have identified that there is a gap between technology developers and ship operators in the adoption of AS. Technology developers are trying to push it out and ship operators are not quick to adopt new technologies due to several reasons. From your perspective, what kind of changes do you feel are needed for AS to start operating in Zeeland? What barriers

need to be overcome? I think there needs to be one barge party that is willing to go for it and has a continuous flow from an origin to a destination for example from us to a destination. A customer or owner of material who wants to improve barge shipment autonomously is needed. This should be a big company with enough money to invest in it, to show to the world how they are adopting AS so that others can see it in practice and choose to adopt themselves. It's also about sustainability and safety. There should be talks with port owners and NSP as we pay them a lot of money for land so they have a large part to play in this. NSP also isn't as big of a port as Rotterdam and Antwerp therefore adopting this technology in Zeeland will put us on the map and help us grow along with showing everybody else that this adoption is possible.

11. Lastly, In your opinion do you feel that autonomous shipping will be operational in Zeeland between now and 2030? I think the first steps will be made but I think it will be containers that will be first to adopt such as container flows from Rotterdam to inland terminals where there is a continuous flow and I think for dry bulk and our area of operations it is a bit too early and that it should be worked out for containers first such as from Rotterdam to Tilburg or Westdorpe, it can be workable. Then once everything is figured out it can then be adopted and used with dry bulk second.

B.4 Dow Transcript

Date- 19/06/2023 10:30
Via- Teams
Company- Dow Terneuzen
Position- Logistics Leader
Purpose of the interview- To find qualitative data about the adoption of autonomous shipping in the liquid bulk industry. Permission is given to record.

1. Could you tell me what line of work your company does? We are a chemical producer which is our core industry which ranges from plastics to coatings. . . etc. In my line of work about the shipping to your customers. Each manufacturing has side/co-products so we at Dow are good at using our bi-products all by ourselves (vertical integration). We operate B2B sales with about 80

2. For the customers you do sell to, which regions would they be located in? Throughout Europe. I am responsible for the operations in Europe.

3. Do you also own and operate European-bound inland vessels? We don't own the vessels, we are only responsible for the production and loading & unloading of vessels with contracts with mutual expectations on how to operate the vessels. It is our manufacturing site shipping to another manufacturing site.

4. Could you identify some of the main costs and limitations with the loading and unloading of vessels? The assets and maintenance, labor is a part of it of course but due to the danger of the cargo, the maintenance is the biggest chunk of the costs. Pressures must be monitored to ensure the loading process is safe. Vessels must be completely clear of previous cargo so no chemical reaction takes place.

5. Throughout the literature, I found that AS can bring a possible business case of using smaller vessels at higher frequencies to maximize ship utilization. From your perspective is this something you would like to see an increase in or would you prefer to work with larger vessels that may arrive less frequently? Storage tanks at terminals increase constantly therefore if you ship smaller amounts how will you ensure that the utilization of the shore tank is at the rate you want it to be? The impact on emission should also be considered because if you ship smaller quantities the emission per metric tonne will be higher. It's a matter of time before we need to start paying for emissions therefore I would be interested because yes we have routes that we sail twice a week but all the other things need to come into account as well. More investigation would be required.

6. So you mentioned that you operate B2B and regular routes you service, with these fixed contract routes, which routes do you have the highest frequencies on with origin and destination that should be a focus on my research for liquid bulk? The route is on the Rhine River from Antwerp Belgium to Lauterbourg in France.

7. When autonomous shipping arrives it is expected that there will be a high investment cost. A trade-off will therefore need to be made with the perceived cost benefits in the long term. What are your thoughts on vessel operators making this trade-off? do you think they will find it beneficial? From the way the industry has worked for the past 100 years, it is a very reserved industry. Buying a barge will cost around 15 million and more for autonomous sailing therefore you need to ensure the return on investment and security of investment of that vessel for a long period, 10 to 20 years for example. Thinking ahead about which customer would invest in a 20-year contract so that money is reserved but this is something that none of the stock exchange companies is interested in as it has a direct impact on your earnings for the next 20 years. The risk is fully on the vessel owners and not a lot of new vessel owners are entering the market due to the large capital needed. Also, there are hardly any vessels that aren't being used at the moment, the demand is there but the long-term commitment to something that isn't secure is a risk for investors. Nobody has decided to do it first so that others can see if it works.

8. It is found through literature that the roles of the human operator are being moved towards a shore control centre in the future, from skipper to controller. Are ships operated without personnel onboard the vessel something that would concern your company for the loading and unloading of vessels given the nature that you operate dangerous cargo? The biggest concern I have is legislation. If legislation allows the transportation of dangerous cargo autonomously with no onboard supervision then that is the biggest risk/concern I have. The technology must be there so that the vessel can moor and stabilise itself during loading as well as for connecting the hoses robotically. I believe in my opinion that autonomous sailing will never happen without any people onboard, I believe sailing can be autonomous but what if something happens with the hoses such as a gasket breaking for example, who will be liable for this? If there is a chemical spill we need to warn local governments and full ownership must be taken for such an accident. Every bit of power must be taken to prevent accidents from happening. From a Dow perspective, we would like to have somebody in person loading and unloading the vessel and operating the hoses and pumps so that responsibility is made. Unmanned sailing is possible but loading & unloading are not.

9. Although the human aspect will still be part of AS operations, I have found that there will be automated systems to help guide the skipper in the early stages of autonomous shipping such as technology for mooring where there is communication between the vessel and the quay. Do you feel investments in these infrastructures to support inland AS should be made by the vessel owners or the terminals? What is the incentive for the terminal would be my answer, what is the benefit for us in doing that? If the current operations are giving me a net profit of millions as a terminal and if the owner wants to shift to an autonomous terminal then I will still make my profit, why invest? It is as simple as if we ship more we will earn more. The 3 parties involved are the vessel operators, the loading parties and the charterers. Each party wants to ship as much as possible therefore technology and legislation should be taken into consideration to keep these 3 parties synchronised.

10. From your perspective, what kind of changes do you feel are needed for autonomous shipping to start operating in Zeeland? What does Zeeland need to do to prepare for AS? Zeeland has limited inland opportunities, there is Terneuzen to Vlissingen. It is around western Scheldt and that's it. For instance, the canal between Terneuzen and Ghent has two countries' legislations involved therefore both must be met. Legislation is the biggest barrier in my opinion. In the next 25 years sustainability will be a large challenge, more so than resource capacity, therefore as soon as a connection where there is a benefit to your emissions then adoption will speed up.

B.5 Vlaeynatie Transcript

Date- 20/06/2023 10:30
Via- Teams
Company- Vlaeynatie
Position- Commercial Director
Purpose of the interview- To find qualitative data about the adoption of autonomous shipping in the dry bulk and container industry. Permission is given to record.

1. Could you tell me what line of work your company does? We are a logistical provider and operate in the sugar and fertilizer industry and we focus on adding value in the supply chain. We bag products in your bagging facilities where we receive products in bulk, bag them, and ship them in containers worldwide. For sugar, we receive in bulk from France, Germany, and Holland and we bag it and ship it. Sometimes we receive packed goods and we have to re-bulk them or into a different bag. We offer barges, trucks, and containers for customers in the sugar and fertilizing industries.

2. Do you also own and operate inland vessels or are you only based on the dry bulk value-adding activities and the tri-modal container hub? We don't own any barges but we go into the market with a few brokers and then we can offer vessels to our customers.

3. Which main costs can you associate with the loading and unloading of inland vessels? Labor is the biggest cost along with the crane, quayside which is always in concession in Western Europe and has to pay for this and we need warehouses to store the goods.

4. I found with dry bulk that weather and late arrivals can impact the speed of the dockside operations and cause a knock-on effect with later arrivals. Is this also apparent in your operations in dry bulk and containers and can you identify any other constraints? Fuel prices, especially last year during the fuel crisis, are increasing and shippers don't want to be paying all this extra money. It is important to keep costs as stable as possible. When brokers are coming for the same vessel and volume from a to b it is 5% more expensive due to high fuel prices and capacities therefore it is not as easy to absorb all the time.

5. What are the most common destinations and origins of the inland vessels you load and unload, is there a typical route you see for container and dry bulk in inland shipping? Into Holland and Germany for sure, we also have a lot of fertilizer factories not far from our location such as Rosier along the Ghent Terneuzen canal and also Yara. Our work with these partners could help to turn these routes into a remote shipping operation. Longer distances are also possible but the flows are not as stable. Our customers are not always selling to the same origins and parties. From our point of view, it will be interesting to develop smart shipping operations.

6. Do you also think AS is possible for container flows in your operation? Yes, for shipping from the North Sea Port to Antwerp there are a lot of journeys being done, and companies who operate in this such as Danser, who is a very strong player and I am quite sure they are also lowering their operational costs with smart shipping. They have the volumes, they often make sure they call at multiple terminals and quayside so that they have the volume so that they can call the large ports (Antwerp) directly.

7. What type of container and dry bulk barge do you generally work with, is there a typical barge type that you load and unload each week? There are multiple kinds of vessels which all depend on length and width. It depends on what the cargo is asking for. For instance, for container vessels, Danser can easily have 3 or 4 vessels of around 40 to 50 containers to the port of Antwerp each day. A smaller player may be only interested in a vessel that can carry 20 containers but also may go up and down every day instead of a large vessel that may only be half-filled or have to make multiple stops. It's the overall volume and the round trips that the vessel can make that should be focused on along with the commitment from the customer. If the customer is willing to commit to a certain volume and revenue then the vessel size doesn't matter.

8. Along with high investment costs in AS technology a trade-off is made between investment and the perceived cost benefits in the long term. Which type of inland shipping operators do you feel will want to make these investments first and adopt and why? We prefer not to make it first, in the ideal world the vessel operators should make this investment first: vessel owners and charter agencies. When we have a vessel coming from A to B and we are B, we can make a fixed contract with A that he brings the goods to us on a weekly basis and this can be for several years (7 or 8 years) and we can do the full logistics for that then we are interested in making that investment as well because we can take this into our business case. To commercialise it and get it started in the Netherlands it is more the big companies such as Maaskade who own I think around 175 barges therefore their operational costs taking into account 2 or 3 crew per barge is a large cost. The first move has to come from vessel owners, a lot are family-owned and are mostly on the spot market. Companies

that group vessels or have their own stable fleet of vessels should make this move first. Somebody needs to do it first for the rest to follow. For example, the Yara Birkeland vessel is not used much today, it is more to show that they are industry leaders and that it's possible but I have not seen this vessel going to a lot of places. Companies with high margins and high revenue should adopt.

9. Reports show that mooring and docking technology make up a large portion of the costs in AS technology and will need to be applied shoreside and onboard. Do you think a shared investment should be made between the port authorities and the vessel operators or only the vessel operators due to their choosing to use autonomous ships? It should be a shared investment. Shipping goods from A to B involves both parties and should collectively pay for this investment. Often when investing for things like that we will ask for a certain level of commitment from our customer so we can secure that investment.

10. I had an interesting discussion with another researcher who is also looking into inland AS about the possibilities of designing a vessel that can carry both containers and dry bulk at the same time. Can you identify any limitations of this, do you think this could be a viable business case? I think it is best to have one industry type on the vessel. It isn't being done today which must be for a certain reason due to something like the stability of the vessel. From an operational standpoint, it isn't realistic to combine both.

11. The move towards automation is found to increase safety due to the level of human error being reduced leading to reduced accidents. To what extent do you feel this increased safety is beneficial to your area of operations? Are there any key safety concerns you have at the moment when loading the container vessels? The fewer people involved with the loading operations the safer it will be but on the other hand if something goes wrong who is liable and how are insurances dealt with? There are safety benefits due to human error such as falling off the vessel and things like that but if accidents don't happen much then it will be questionable. The intensity of operations is always increasing therefore we shouldn't keep trying to expand port areas and use up more land, operations and logistics should become more reliable and efficient which can make things safer.

12. Throughout the literature, I found that in the future autonomous shipping systems on the ship can integrate with cargo management systems in the port for more efficient loading and unloading processes and more accurate cargo planning. Is this something that companies located in Zeeland with IWT access are open to or do you feel that this level of data sharing has its flaws? When it is a fixed setup and everything is covered in contracts then why not? This level of data sharing can add additional efficiency. For contract agreements, we want to make sure all parameters about the cargo and the level of care are there from both parties to have the exact specifications so that mistakes and delays are avoided.

13. From your perspective, what kind of changes do you feel are needed for autonomous shipping to start operating in Zeeland? What does Zeeland need to do to prepare for AS? A better internet network is needed. The quality of the data network (4/5g) is very bad near the border of Belgium therefore if vessels aren't able to connect because of this reason then it is an issue in our region. North Sea Port still has much space therefore AS infrastructure is possible to adopt such as sensors and beacons which isn't possible in the busier ports such as Antwerp and Rotterdam.

14. Is autonomous shipping something you feel is coming between now and 2030? To what degree? Yes, it is happening already in Belgium but we in the Netherlands are limited to legislation. An additional push from the EU might be needed to move this forward. The reduction of skippers in Europe is something that barge operators are very concerned about therefore this solution must be made.