Journal of Shipping and Trade

REVIEW

Open Access

# Identifying innovation factors and actors in autonomous inland shipping: a literature review

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**Abstract**

Autonomous shipping is introduced to increase the competitiveness of inland shipping and promote a modal shift toward sustainable transport. This innovation has the potential to disrupt the existing inland shipping industry paradigm. This paper identifies the characteristics of autonomous inland shipping through the lens of the diffusion of innovation theory. A systematic literature review, based on the PRISMA 2020 guidelines methodology, was conducted. The existing literature aligns well with the theory and reveals most of the innovation variables and relevant actors. The result indicates that the literature on this topic is limited but still developing, and the paper presents opportunities for agendas in business, innovation, and transportation research. Further discussion shows industry implications, using a generalized transport cost model and stakeholder analysis to emphasize the motivations for sustainable transport through the adoption of autonomous shipping.

**Keywords:** Autonomous shipping, Inland waterways transport, Diffusion of innovation

## Introduction

The projected increase in freight transport to over 80% by 2050 is expected to place a heavy burden on transport networks and the environment (European Commission 2011). Furthermore, the transport sector contributes to a quarter of the EU's total greenhouse gases (GHGs) emissions (Commission 2024). Many actions have been introduced to promote the modal shift towards sustainable transportation modes. For example, initiatives such as the European Green Deal, pilot projects, and research projects (2022). There are three major inland freight transport modes in Europe: road, railways, and inland waterways transport (IWT) or inland shipping (Eurostat 2022). The European Commission introduced the European Green Deal as a new sustainable growth strategy, with a commitment to shift 75% of current inland freight transport to railways and inland shipping (Commission 2024).

United Nations recognizes that different transport modes have different advantages and disadvantages for example in speed, reliability, accessibility, cost, safety, security, capacity, and market niches (United Nations 2015). Inland shipping is a transport mode limited by geographic boundaries due to its nature in optimizing waterways (Al Enezy et al. 2017). Inland shipping cargo volume is calculated in ton-kilometer (TKM) and the operation is based on transport corridors on rivers (CCNR 2021). The four main inland shipping freight corridors in Europe are the Rhine River Corridor, the Danube Corridor, the East–West Axis, and the North–South Axis, with total of 15,000 km of navigable waterways (Beelen 2011).

Inland shipping is characterized as low cost, safe, and less noisy compared to other inland freight transport modes (Essen, et al. 2019). It also accounts for a small fraction of transport accidents (0.3%) compared to road transport (97.5%) (Essen, et al. 2019). The waterways can be optimized for a more cost-effective logistics chain using a network of rivers and canals (Stopford 1997). A study by the United Nations also finds that inland shipping is fifty times safer than road transport and five times safer than railways in terms of persons killed per ton-km (United Nations 2015). However, inland shipping has the lowest modal share among inland transport modes compared to road and railway transport in Europe (Eurostat 2022). This indicates that inland shipping cannot compete with other inland freight transport, such as road and railways.

Two common initiatives promoting a modal shift in transportation are digitalization and automation. Autonomous shipping has the potential to transform the supply and logistics chain (Tsvetkova and Hellström 2022). There are two major branches in the diffusion of innovation research domain: the Classic and Institutional Theories (Bui 2015). This paper uses Classic Theory, specifically Rogers' diffusion of innovation theory, as a framework (Rogers 2003). Different diffusion of innovation theories comparisons will be discussed in a later section. In innovation research, recognizing the "attributes of innovation" is considered a vital element for successful implementation (Wisdom et al. 2014). Some articles demonstrate the use of the diffusion of innovation theory in the context of transport studies. A literature review finds the diffusion of innovation characteristics of Autonomous Vehicles (AVs) (Silva et al. 2021). Another paper integrates diffusion and behavioral theories in a survey to better understand public acceptance of AVs (Yuen et al. 2021).

Prior literature has explored autonomous ship innovation for ocean transport (Wiśnicki et al. 2021; Li and Yuen 2022; Ziajka-Poznańska and Montewka 2021; Alamoush et al. 2024a). The autonomous shipping is less frequently addressed in the innovation research domain than in other industries (Li and Yuen 2022). Currently, no prior literature review has been done about autonomous shipping for inland shipping. A noticeable knowledge gap exists in the existing body of literature on this topic (Miles 2017). Therefore, this paper aims to identify and compile the variables affecting the adoption rate from published articles, based on a diffusion of innovation model. The research question is, "*Which variables influence the adoption rate of autonomous inland shipping*?". This paper also illustrates the possible changes in the generalized transport cost model due to the introduction of autonomous shipping and subsidies. Additionally, this paper identifies the relevant stakeholders involved and their positions based on their power and interest.

This paper contributes to both academia and policymakers. The proposed framework illustrates how the existing literature perceives different variables to be correlated and suggests extensions to an existing model. Furthermore, the literature review can be useful for policymakers as it provides an overview of factors supporting the implementation of autonomous inland transport solutions. This paper is designed following the literature review guidelines (Wee and Banister 2016). It is structured as follows: Sect. "Introduction" provides the rationale and objectives of the paper. Sect. "Literature review" Literature Review covers the materials and theoretical background needed for the analysis. Sect. "Methodology" outlines the methodology used in the paper. Sect. "Results" presents the results. Sect. "Discussion and conclusion" offers a discussion, a future research agenda, and concludes the paper.

## Literature review

### Inland shipping in Europe

Inland shipping modal share has experienced a declining trend over the past six years in Europe, reaching a level of 5.8% in 2020, in contrast to road transport at 77.4% and railway transport at 16.8% (Eurostat 2022). In the Rhine River area, the demand for inland transport has grown by 41% in the past 15 years, but the volume share has only increased by 16% (Conference and of ministers of transport. and organisation 2006). The modal share of inland transport in Europe from 2015 to 2020 is illustrated in Fig. 1 below.

The generalized transport cost model can explain why inland shipping is less competitive compared to other inland freight transports, such as railway and road transport. The generalized transport cost model considers the perspective of the shipper, where the total cost (*G*) is the sum of the price for transport service (*P*), transport cost or time cost per hour (*H*) multiplied by transport time (*T*), and external costs (*C*) (Hanssen et al. 2012). When the relationship between price and transport distance is compared, road transport has the lowest cost for short distances, railways become cheaper than road transport after some distance, and waterways transportation only becomes the cheapest for longer distances (Mathisen et al. 2015). This model is supported by data showing that road transport dominates the freight market for short distances (under 550 miles), accounting for almost 80% of total domestic freight (United Nations 2015).

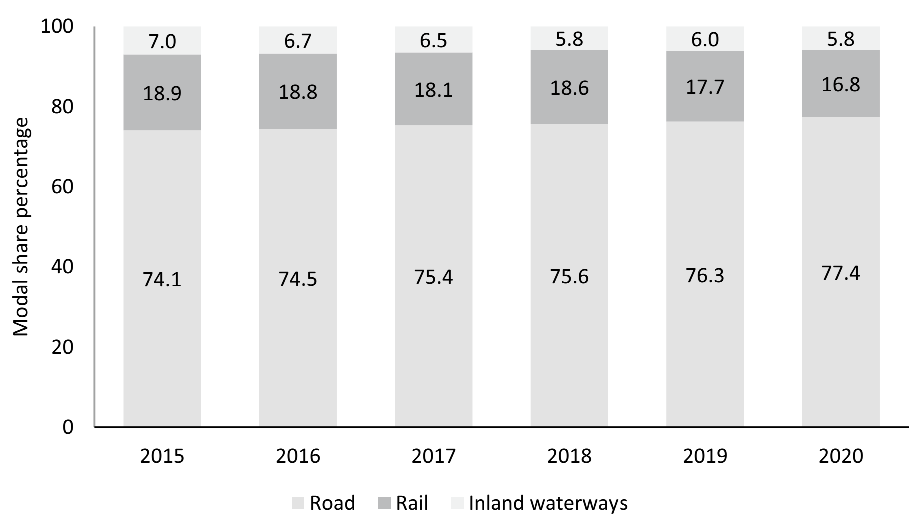


**Fig. 1** Modal split of inland freight transport (in ton-kilometers) in the EU by percentage, 2016–2020 (Eurostat 2022)

This cost model and data explain why the modal share of inland shipping is the lowest among inland freight transport in Europe. The distances are relatively short where cargo is transported domestically or between a few neighboring countries connected by road infrastructure. The equation of the generalized transport cost model is shown in Eq. 1 below (Hanssen et al. 2012).

$$G = P + HT + C \tag{1}$$

In 2022, there are 5,867 registered European inland freight vessels, comprising 4,922 EU vessels and 950 non-EU vessels (Clarksons Research 2022). The five most dominant inland freight vessels in Europe are chemical/product tankers (18%), general cargo vessels (17%), chemical tankers (11%), pontoons (5%), and deck cargo pontoons (4%) (Clarksons Research 2022). The Netherlands has the highest number of vessels with 2,608, followed by Germany with 984, Belgium with 546, and France with 181(Clarksons Research 2022). Among non-EU countries, Russia leads with 259 vessels, followed by Switzerland with 253 vessels, the United Kingdom (UK) with 148 vessels, and Norway with 78 vessels (Clarksons Research 2022). The primary types of goods transported by inland shipping in Europe include metal ores (25.5%), petroleum coke and refined petroleum products (15.3%), chemicals, rubber, plastic, and nuclear fuel (11.9%), and agricultural products (10.9%) (Eurostat 2022).

Compared to other shipping transports, inland shipping has similarities with the Short Sea Shipping (SSS). Both inland and short sea shipping operate in certain regions or corridors, in contrast to ocean shipping (CCNR 2021; Beelen 2011; Gribkovskaia et al. 2019). From the perspective of autonomous shipping innovation, this similarity will affect the nature of autonomous operations, where Remote Control Centres (RCC) can be stationed on land based on the location of the operation. Both industries also face the same crew shortage and late adoption of innovation (Al Enezy et al. 2017; CCNR 2012; Ghaderi 2019). Conversely, these two shipping transport modes also have some differences, including the type of ships and the business model of the industry. The three most commonly used ships in short sea shipping are general cargo, RoRo (roll-on/roll-off), and tankers (Gribkovskaia et al. 2019).

Inland shipping relies heavily on crews for its operation (Stopford 1997). Personnel costs are estimated to account for approximately 26% of the total cost of an inland dry cargo-container ship in the time charter scheme (Al Enezy et al. 2017). In 2020, due to the pandemic, approximately 200,000 seafarers remained on board vessels, with a similar number urgently needing to join ships (Allianz global corporate specialty 2021). There is a trend of aging and unattractive prospects in the inland shipping industry (Wiegmans and Konings 2015). These are the current challenges faced by the inland shipping industry.

### Autonomous shipping

Autonomous shipping innovation has the potential to lower costs, reduce emissions, and decrease dependence on human labor (Wiegmans et al. 2015; Ziajka-Poznanska and Montewka 2021). The automation of maritime transport could also stimulate economic growth and facilitate the development of policy tools (United Nations 2024). The concept of autonomous shipping has now reached a level of maturity with proven technical feasibility (Ventikos et al. 2020). However, there are indicated increased costs associated with the Remote Control Centre (RCC), maintenance, port calls, and the implementation of new technologies (Kretschmann et al 2017). Nevertheless, there are still uncertainties about future changes in insurance, cyber security, and external costs (Ziajka-Poznanska and Montewka 2021). Consequently, a greater focus on these areas is required to reduce uncertainty and support the implementation of autonomous shipping in both ocean and inland transport.

The regulatory organization in inland shipping has different interpretations of what qualifies as an autonomous ship with the International Maritime Organization (IMO). The IMO defines a Maritime Autonomous Surface Ship (MASS) as a ship capable of operating independently without human interaction at four different degrees (IMO 2021). Degree One is a ship with automated process and decision support, Degree Two is a remotely controlled ship with seafarers on board, Degree Three is a remotely controlled ship without seafarers on board, and Degree Four is a fully autonomous ship (IMO 2021).

In contrast, the Central Commission for the Navigation of the Rhine (CCNR), an administrative body overseeing inland navigation on the Rhine River, defines six degrees of autonomy levels (CCNR 2018). Level Zero is no automation, Level One is steering assistance, Level Two is partial automation, Level Three is conditional automation, Level Four is high automation, and Level Five is autonomous or full automation (CCNR 2018). It is important to address this distinction as this paper focuses on inland shipping, and therefore, it follows the CCNR's guidelines. The level of automation is defined as the extent to which an automated ship can operate during its journey (CCNR 2018). This paper explores the broader definition of autonomous ships, covering all autonomy levels.

### Diffusion of innovation theory

There are several theoretical frameworks for analyzing innovation adoption. A comparative paper identified that Rogers' and Valente's innovation adoption theories are the only two suitable theories for cross-disciplinary analysis (Wisdom et al. 2014). Classic Diffusion theories, such as Rogers', are more effective at explaining an individual's decision to adopt innovation than Institutional Diffusion and Cognitive-Institutional Diffusion theories (Bui 2015). The reason is that Classic Diffusion theories are based on direct benefits, while Institutional Diffusion focuses on indirect benefits, and Cognitive-Institutional Diffusion centers on collective reasoning (Bui 2015). Therefore, Rogers' diffusion of innovation theory is used because it suits the purpose of this paper.

According to Rogers' (2003), there are different categories of innovation adoption actors, including innovators, early adopters, early majority, late majority, and. The individual (consumer) and organizational (firm) innovation adoption is different, the organizational innovativeness is affected by leaders' individual characteristics, internal organization structure, and external characteristics. Meanwhile, the consumers-adopters' rate of adoption is a dependent variable stemming from five independent variables: perceived attributes of innovation, type of innovation decision, communication channel, nature of the social system, and promotional efforts. Some more recent research highlighted the distinction (Alamoush 2024; Garcia 2007; Bianchi et al. 2017). This paper considers the consumer adopters' perspective, and the variables are more naturally related to socio-economic research than technical or operational studies. Therefore, the methodology restricts the focus to literature related to socio-economic factors.

#### *Perceived attributes of innovation*

The perceived attributes of innovation are influenced by relative advantage, compatibility, trialability, and observability (Rogers 2003). However, the attributes are not fixed, as some actors may find other variables influencing the adoption process. Therefore, scholars are advised to maintain an open-minded approach to variables related to the attributes of innovation (Rogers 2003).

Relative advantage refers to the extent to which an innovation is perceived as better than the current product (Rogers 2003). This variable can be economic, social, environmental, efficiency, or other benefits related to the innovation market. Compatibility relates to the degree to which the innovation is perceived as consistent with existing values, past experiences, and the potential needs of the user (Rogers 2003). Compatibility can also translated to social and cultural values, previous ideas, and client needs (Silva et al. 2021). Complexity represents the degree to which the innovation is perceived as relatively easy or difficult for current actors (Rogers 2003). The easier the innovation is to use, the more motivated the actors are to adopt it. Trialability reflects the extent to which an innovation can be tested in an actual setting (Rogers 2003). Triable innovation presents less uncertainty to individuals as it allows them to learn by doing. Observability pertains to the degree to which the results of innovation are visible (observed and reported) to others (Rogers 2003). Observability can be equated with public contributions through publications, pilot projects, and research.

#### *Types of innovation decision*

The innovation-decision process involves an individual gaining initial knowledge of an innovation, forming an attitude toward it, deciding whether to adopt or reject it, implementing it, and ultimately confirming the decision (Rogers 2003). This process consists of five consecutive stages linked with a communication channel, including knowledge, persuasion, decision, implementation, and confirmation (Rogers 2003). Innovation that requires many people's decisions tends to be adopted more slowly.

There are three types of innovation decisions: optional, collective, and authority (Rogers 2003). The first two types of innovation decisions tend to be adopted more quickly than the authority type. In the optional type, decisions are made by autonomous or independent agents. Meanwhile, in the collective type, decisions are made by consensus among system members. In contrast, in the authority type, relatively few individuals make decisions with specific power, status, or expertise.

#### *Communication channel*

Information exchange among actors in the social system is at the core of the innovation diffusion process (Rogers 2003). This process involves four key variables: the innovation, the individual with knowledge of the innovation, the individual without knowledge, and the communication channel connecting them. Depending on the nature of the innovation, personal and general public communication media can affect an actor's adoption differently.

The communication channel is the medium through which messages travel from one individual to another (Rogers 2003). The relationship between communication channels and the rate of adoption is complex and somewhat challenging to explain in general terms. The communication channel plays different roles for different actors within a system. One way to classify communication channels is to categorize them as either interpersonal or mass media. The interpersonal channel involves the diffusion of information between individuals, while the mass media channel encompasses the use of mass media platforms such as radio, television, newspapers, and others (Rogers 2003). The media channel is more influential during the knowledge stage, whereas the interpersonal channel is more important during the persuasion stage (Rogers 2003).

#### *Nature of the social system*

A social system is a collection of interrelated and engaged agents collaborating in joint problem-solving to achieve a common goal (Rogers 2003). The members of this system cooperate to varying degrees, share a common objective, and are interconnected within the system. These agents are not identical, which creates a unique structure that impacts the diffusion process (Rogers 2003). This structure can either promote or demote the diffusion of innovation.

There are two key factors related to the nature of social systems: norms and interconnectedness (Rogers 2003). Norms are defined as established behavioral patterns of the system members, serving as standards or guides for their actions. Therefore, norms can act as barriers to innovation if they resist change. Interconnectedness refers to the degree of units linked by interpersonal networks in a social system. It is positively correlated with the rate of adoption (Rogers 2003). Innovations can be more easily and quickly diffused within a social network with a higher number of interconnected agents.

#### *Change agent promotion*

There are certain individuals in a social system have specific roles in the diffusion process, including opinion leaders and change agents (Rogers 2003). While opinion leaders are considered informal leaders or social models, change agents are the linkers. It is crucial to acknowledge change agents in a social system as their facilitators in the flow of innovation from a change agency to an audience.

A structured campaign is necessary to promote the adoption of innovation. A campaign is a deliberate and purposeful action designed to achieve a specific effect (Rogers 2003). Additionally, there are two types of diffusion systems related to change agents: centralized and decentralized (Rogers 2003). In centralized diffusion, change agents are positioned between research and development and opinion leaders. In contrast, in decentralized diffusion, change agents are part of horizontal flat networks.

### Stakeholders

The previous discussion introduced the significance of different agents and the role of change agents within the diffusion of innovation theory. Next discussion covers the stakeholders. Stakeholders are the interest groups in the promoted policy (CCNR 2012).

Stakeholders have varied interests in the business, influenced by their business-related characteristics (Rogers 2003). One way to identify different stakeholders in a business is through stakeholder mapping, a method for categorizing various actors based on their attributes, such as power, interest, contribution, and other factors (Dobrzyński et al. 2015). The most commonly used attributes in stakeholder analysis are power and interest (Dobrzyński et al. 2015; Schmeer 2000; Kristen 2015; Ackermann and Eden 2011). The findings can then be presented in a four-quadrant matrix based on the impact of these attributes (Ackermann and Eden 2011). Different groups of stakeholders are treated differently using this method, resulting in four groups: the players, the subjects, the context setters, and the crowds (Ackermann and Eden 2011). This paper presents the result in a power-interest stakeholder mapping based on the published literature, following the suggested approach (Ackermann and Eden 2011). This method is widely employed in organizations in different industries due to its practicality.

## Methodology

This paper utilizes a structured literature review (SLR) methodology to provide updated and structured information from specific studies (Wee and Banister 2016). The PRISMA 2020 guidelines and 27-item checklist were followed to facilitate better evaluation and possible replication (Page et al. 2021). The PRISMA 2020 diagram flow template was also followed and is shown in Fig. 2. Implementing SLR with PRISMA 2020 benefits authors, editors, and readers by providing transparent and thorough reporting based on data (Page et al. 2021).

This paper used two identification methodologies: datasets and researchers' recommendations. The datasets identification method utilized Scopus and Web of Science

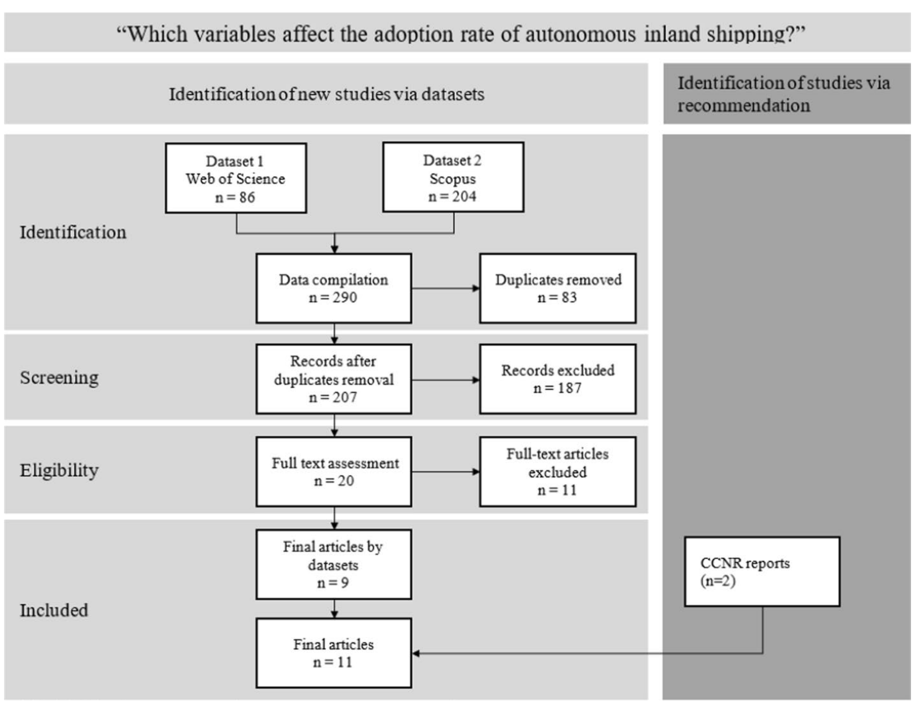


**Fig. 2** Data selection flowchart

(WoS) datasets. Additionally, researchers' recommendations were incorporated after the paper draft was presented at several conferences. The selection of Scopus and Web of Science for datasets identification was based on their feature of providing peer-reviewed works exclusively. Scopus offers a wide range of journals, resulting in a higher number of articles provided compared to other peer-reviewed datasets (Aghaei Chadegani, et al. 2013; Falagas et al. 2008; Mongeon and Paul-Hus 2016). Meanwhile, WoS covers journals with a higher impact factor (IF) (Aghaei Chadegani, et al. 2013). Although it provides alternative results, Google Scholar was excluded due to its inclusion of inadequate information (Falagas et al. 2008).

Data collection was conducted in July 2022, with predetermined filters and criteria, including keywords, publication year, article language, and article types. As mentioned in the earlier section, the result is to include only socio-economic studies. The keywords were formulated based on a preliminary literature review. Short sea shipping is also included with inland shipping due to their operational similarities in perspective of autonomous shipping. The publication year was limited to the start of the year 2000 to maintain relevance. Data collection encompassed all articles globally published in English. The detailed data collection filter and criteria are shown in Table 1 below.

## Results

The search yielded 86 articles from Web of Science (WoS) and 204 articles from Scopus. Then, data compilation and duplicate removal were conducted using a spreadsheet, resulting in 207 articles. The next step involved screening by titles and abstracts, with 20 articles included for full-text assessment and 186 articles excluded. The records excluded in this phase, such as the autonomous aerial transport research domain, did not align with this paper's aim.

Text assessment led to the selection of nine final articles from dataset identification. In addition to the datasets, two reports from CCNR were added based on researchers' recommendations. This approach was justified by considering CCNR's status as a respected international organization that provides the latest updates on the market, innovation, and data related to the inland shipping industry. The first included report is the *International Definition of Levels of Automation in Inland Navigation* (CCNR 2018), and the second report included is the *Thematic Report: An Assessment of New Market Opportunities for Inland Waterway Transport* (CCNR 2022). In total, eleven articles were selected: nine from dataset identification and two from recommendations. The complete data selection flowchart is shown in Fig. 2 below.

**Table 1** Data collection filters

| Filter/criteria | Value |
| --- | --- |
| Keywords | "autonomous" or "unmanned" and "inland" or "waterway*" or "short." |
| Publication Year | 2000–2022 |
| Language | English |
| Article type | Journal article, conference article, and book chapter |

Access to journal articles, reports, and book chapters is available online. Meanwhile, two conferences articles were provided upon personal requests (Gribkovskaia et al. 2019; Rajapakse and Emad 2019). The final articles selection resulted in eleven records, including six journal articles, two conference articles, two reports and one book chapter. The publication year and document type of the final selection are shown in Table 2 below.

The final article selection indicates that the topic is still relatively new and emerging. There were no published articles between 2000 and 2018, and research interest has steadily grown since that time. Among the selected articles, four articles include"short sea" in their titles, while seven use variations of"inland waterway" or"inland shipping". Most of the articles (seven) incorporate the keyword"autonomous", three articles use the keyword"unmanned", and one CCNR report does not include any related keywords.

The next subsections cover the findings and discussion of the innovation factors related to autonomous shipping for inland shipping. This paper compares the innovation (autonomous shipping) with the existing norms (current inland shipping operations). The section concludes with a summary, generalized cost of transport after the implementation of autonomous shipping, and stakeholder analysis, presented in a matrix of power and interest.

## Perceived attributes of the innovation

### *Relative advantages*

Several advantages of autonomous shipping for inland shipping have been identified, including lower crew costs, safer operations, increased efficiency, reduced capital and

**Table 2** Final articles included in the analysis

| Publication year | Authors | Title | Articles type |
|---|---|---|---|
| 2018 | Kooij et al. | Towards autonomous shipping: operational challenges of unmanned short sea cargo vessels | Book chapter |
| 2018 | Ghaderi | Autonomous technologies in short sea shipping- trends, feasibility, and implications | Journal article |
| 2018 | CCNR | First international definition of levels of automation in inland navigation | Report |
| 2019 | Rajapakse & Emad | A review of technology, infrastructure, and human competence of maritime stakeholders on the path towards autonomous short sea shipping | Conference article |
| 2019 | Gribkovskaia et al. | Autonomous ships for coastal and short-sea shipping | Conference article |
| 2019 | Zhang et al. | Safety Risk Analysis of Unmanned Ships in Inland Rivers Based on a Fuzzy Bayesian Network | Journal article |
| 2019 | Verberght & van Hassel | The automated and unmanned inland vessel | Journal article |
| 2020 | Backalov | Safety of autonomous inland vessel: an analysis of regulatory barriers in the present technical standards in Europe | Journal article |
| 2021 | Nzengu et al. | Regulatory framework analysis for the unmanned inland waterway vessel | Journal article |
| 2021 | Akbar et al. | An economic analysis of introducing autonomous ships in a short-sea liner shipping network | Journal article |
| 2021 | CCNR | Thematic report–an assessment of new market opportunities for inland waterway transport | Report |

operational costs, improved working conditions, and decreased external costs (Gribkovskaia et al. 2019; Rajapakse and Emad 2019; Akbar et al. 2021; Bačkalov 2020; Verberght and Hassel 2019). One of the most commonly cited advantages of this innovation is the significant reduction in crew costs. The reduction or elimination of crew costs is particularly beneficial in high-cost countries, such as Norway (Akbar et al. 2021). Reducing the human factor in operations also contributes to a safer operational environment (Akbar et al. 2021; Bačkalov 2020; Verberght and Hassel 2019). However, it is essential to note that implementing an autonomous system on board should not be seen as the elimination of safety risks but rather as an improvement in risk mitigation (Bačkalov 2020).

Implementing autonomous ship can reduce inland shipping operational costs (Ghaderi 2019). The adoption of newer technology is expected to increase efficiency (Rajapakse and Emad 2019). Additionally, the fuel cost is estimated to be 5% lower than that of a conventional vessel with the same cargo capacity, thanks to space and design optimization (Akbar et al. 2021; Verberght and Hassel 2019). The vessel is expected to have lower emissions than a conventional vessel due to its lighter design and more efficient sailing (Verberght and Hassel 2019). Other operational costs, including communication and administrative expenses, are also predicted to decrease significantly (Verberght and Hassel 2019).

Autonomous inland shipping operations are expected to align with current business trends in other transport modes. A subscription business model in autonomous inland shipping has the potential to reduce both capital and operational costs (Ghaderi 2019). Another article predicts a business model similar to ride-hailing technology in road transport, suggesting that Uber-like services could reduce costs (Rajapakse and Emad 2019). Furthermore, optimizing operations with an autonomous mother-daughter vessel scheme could lead to an additional reduction in operational costs by 11–20% (Akbar et al. 2021). Chartering or freight broker service fees are anticipated to decrease (Verberght and Hassel 2019). Brokerage services are predicted to become obsolete with the advancement of technology (Rajapakse and Emad 2019).

The new design of autonomous ships would mean that ship maneuvering is primarily onshore, offering better working conditions than onboard operations (Bačkalov 2020). This change could simplify the recruitment process for future employees with higher competence (Rajapakse and Emad 2019). The automated operation is also projected to reduce external costs, including those related to congestion, accidents, and emissions (Verberght and Hassel 2019). It is worth noting that the current operations are already considered safe and would likely further improve.

#### *Compatibility*

The literature provides indications that autonomous inland shipping aligns with the values and norms of the current business. Reducing the crew on board would answer the current needs driven by the aging and shortage growth of crews in the European inland shipping industry (Verberght and Hassel 2019). The significance of reducing crew costs and achieving higher environmental targets through innovation has increased over the years, especially in North-West Europe, such as Norway (Gribkovskaia et al. 2019). The implementation of autonomous shipping supports the current stakeholders' vision for productivity and competitiveness improvement (Rajapakse and Emad 2019).

Staying competitive in the field of inland shipping requires a strong emphasis on innovation (Verberght and Hassel 2019). Short sea shipping (SSS) is facing competitiveness challenge as it has not gained technical and productivity improvement as fast as the ocean transport industry(Ghaderi 2019). As mentioned in the previous section, autonomous shipping innovation will enhance safety by addressing human factor, which is a leading cause of marine accidents (Zhang et al. 2019). Autonomous shipping may align with the current industry's values and also offer solutions to its existing challenges.

#### *Complexity*

Implementing this innovation will create a new demand for employees with critical thinking, decision-making, and information technology (IT)-related skills in the future (Rajapakse and Emad 2019). Inspectors will also require knowledge of automated vessels, on-board technology, and specialized training (Verberght and Hassel 2019). Additionally, operational challenges, including situational awareness, external communication, crew interaction, maintenance and repair, will arise (Kooij et al. 2019). Internal verbal communication will become obsolete and be replaced by the Remote Control Centre (RCC) in autonomous inland shipping (Kooij et al. 2019). There will be a paradigm shift towards safety measures through the RCC (Bačkalov 2020). The implementation of autonomous shipping will introduce new cost components, such as RCC cost (Akbar et al. 2021). Moreover, there are also financial risks for shipowners, banks, and insurers related to the unpredictability of autonomous shipping (Ghaderi 2019). These additional costs may reduce investment attractiveness, especially for small operators (Ghaderi 2019).

Currently, only limited data and reports on autonomous shipping are available, which makes conducting studies challenging (Zhang et al. 2019). New regulations will facilitate autonomous operation in inland shipping (Rajapakse and Emad 2019; Bačkalov 2020; Verberght and Hassel 2019; Kooij et al. 2019; Nzengu et al. 2021). The absence of a vessel owner board has raised liability issues (Verberght and Hassel 2019). Moreover, the adoption of autonomous ships is challenged by the lack of a regulatory framework (Kooij et al. 2019). The regulation development and amendment are time-consuming and may lead to slow adoption (Kooij et al. 2019). European inland shipping regulation is disintegrated, with no single international governing institution, such as the International Maritime Organization (IMO) for sea transport (Bačkalov 2020).

#### *Trialability*

The implementation of autonomous inland shipping will require several approvals from different authorities (Nzengu et al. 2021). For example, in Flanders, Belgium, there are three local organizations related to inland shipping: De Vlaamse Waterweg NV (DVW), Maritieme Toegang (MT), and Maritieme Dienstverlening en Kust (MDK) (Kooij et al. 2019). This high hierarchy could pose a challenge for pilot projects conducting trials. However, trialability is being promoted by recent initiatives from the public, companies, and other stakeholders' projects involving automation in Europe. For example, the Flemish authorities have agreed to facilitate the prototype on their waterways (Verberght and

Hassel 2019; Kooij et al. 2019). The Rhine River regulatory body, CCNR, showed its support by providing the first international definition of levels of automation in inland navigation in 2018 (CCNR 2018). It is predicted that national water regulations will develop faster than international regulations toward autonomous ships (Akbar et al. 2021).

#### *Observability*

Several projects and research on autonomous inland shipping are accessible to the public. In Europe, various research initiatives exist, including the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project by the European Union, the Advanced Autonomous Waterborne Applications Initiative (AAWA) by Rolls-Royce, the zero-crew vessel concept, ReVolt by DNV-GL, and AUTOSHIP projects (Kooij et al. 2019). The European Union financed the MUNIN Project to assess the feasibility of autonomous shipping (Ghaderi 2019). Other emerging projects include Roboat, A-SWARM, and AVATAR projects (CCNR 2022). AVATAR is a pilot project funded by the European Union, focusing on autonomous inland shipping of urban and waste cargo (CCNR 2022). Norway hosts two ongoing projects: Yara Birkenland, the first commercial autonomous ship, and autonomous passenger ferry development by NTNU (Akbar et al. 2021). Autonomous shipping projects are also being developed outside Europe, such as the Unmanned Cargo Ship Development Alliance (UCSDA) by the HNA Group in China (Zhang et al. 2019). These efforts demonstrate the broad reach of stakeholders aiming to engage a more general public audience.

### Type of innovation decision

There are different regulatory bodies regulating the operation of inland shipping (Nzengu et al. 2021). The local and regional regulatory bodies serve as facilitators of autonomous inland shipping innovation (Bačkalov 2020; Verberght and Hassel 2019; Kooij et al. 2019). It would be challenging for shipowners to justify the adoption financially without considering external costs, such as accident, infrastructure, and emission costs (Verberght and Hassel 2019). The new building cost of an autonomous inland ship is predicted to be 5% to 300% higher than that of a conventional ship (Akbar et al. 2021; Verberght and Hassel 2019). An estimated 20% additional port fee is attributed to the extra assistance required (Akbar et al. 2021). There is currently no explicit external funding available for ship owners investing in this innovation (Verberght and Hassel 2019). Therefore, the decision to adopt autonomous inland shipping for a shipping company is likely optional, influenced by the system's norms and interpersonal networks (Rogers 2003).

### Communication channels

Several actors have been identified in the papers, including shipping companies (shipowners), terminal operators, ports, flag states, regional and local regulatory bodies such as CCNR and Comité européen pour l' élaboration de standards dans le domaine de navigation intérieure (CESNI), and communication providers, including Vessel Traffic Services (VTS), Sea Traffic Management (STM) operators, and RCC (Rajapakse and Emad 2019). As the observability section mentions, several public projects are implementing mass media communication channels. Unfortunately, no article explicitly indicates the dynamics of interpersonal communication channels involved in autonomous inland shipping innovation. The internal communication structure remains non-visible, as no prior research has managed to capture it.

#### Nature of the social system

Implementing autonomous inland shipping would require a new business model because the current ship manufacturing industry is saturated (Rajapakse and Emad 2019). The current inland business model in the Rhine River region is more family-oriented, with living or office accommodations onboard, or a vessel owner/operator (VO/O) model (Verberght and Hassel 2019). This business model will face a significant norm barrier towards the changes offered by the autonomous inland shipping innovation. Meanwhile, the entry barrier is considered high in the inland transport industry; thus, the change must first be internal (Akbar et al. 2021). The inland shipping industry is considered a niche market with strong norms and interconnections between agents.

#### Change agent promotion

As described above, there are different actors related to the innovation. Still, shipping companies are positioned at the center of this innovation and will both benefit and face losses due to the new implementation (Ghaderi 2019; Akbar et al. 2021). Meanwhile, shipowners have personal attachments to their business (Verberght and Hassel 2019). Promotion efforts must consider the change agents who connect directly with shipowners and deliver the message effectively. There is no clear indication of overall control of the decision, even though there is high involvement of local and regulatory bodies to facilitate the adoption (Verberght and Hassel 2019; Kooij et al. 2019). This lack of clear control leads to interpreting the decentralized diffusion system hierarchy of autonomous inland shipping. Promotion efforts should consider inland shipowners as the agents of change for their peers.

### Summary of the literature and determinant variables in the technology adoption

Current literature has explained or indicated most of the autonomous inland shipping innovation variables, except for intrapersonal communication channels between actors. The summary of innovation variables affecting the technology adoption rate from the reviewed literature is shown in Fig. 3 below.

#### Generalized cost of transport

The introduction of autonomous shipping for inland shipping will reduce the price of transport services (*P*) due to lower crew, capital, and operational costs (Gribkovskaia et al. 2019; Rajapakse and Emad 2019; Akbar et al. 2021; Bačkalov 2020). It will further reduce with the new business model introduction, such as collective transport hauling (Rajapakse and Emad 2019; Akbar et al. 2021) and diminishing broker fee (Akbar et al. 2021; Verberght and Hassel 2019). However, on the other hand, transport costs will increase with higher time costs per hour (HT) because of additional services related to autonomous shipping and new cost components, such as the RCC (Bačkalov 2020; Kooij et al. 2019). But, transport time will decrease with navigation assistance and

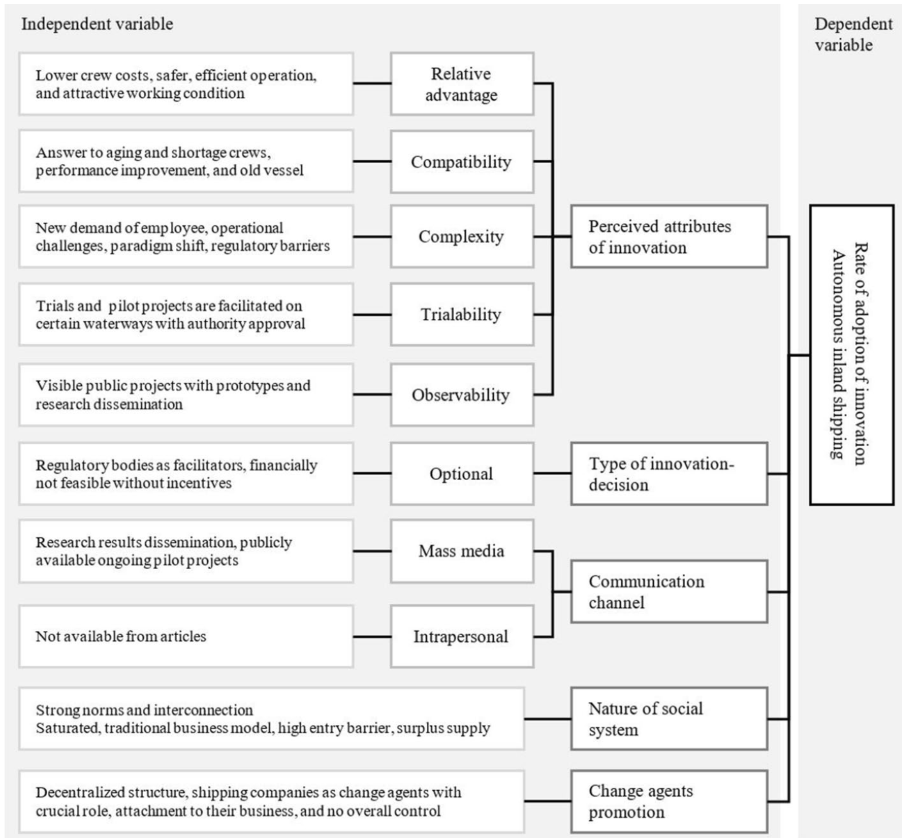


**Fig. 3** Innovation variables of autonomous inland shipping (results)

overall increased efficiency (Rajapakse and Emad 2019). External costs (C) will also be reduced due to improved working conditions, lower emissions from increased efficiency, improved risk mitigation with embedded systems onboard, and reductions in congestion and accidents (Bačkalov 2020; Verberght and Hassel 2019). Another relevant factor for the implementation of new technology is the subsidy (S) which is the moderating variable of price (P). The European Commission is committed to sustainable transport modes through the European Green Deal (Commission 2024). This could result in a subsidy policy scheme for inland shipping, which can further lower the cost of this transport mode. The generalized transport cost taking into consideration the introduction of subsidy (S) is shown by Eq. 2 below.

$$G = (P - S) + HT + C \tag{2}$$

The combination of autonomous shipping innovation and subsidies for inland shipping would reduce the marginal cost for transporting an extra unit of cargo by this transport mode. Consequently, the generalized cost curve for inland shipping after the autonomous improvement (indicated by w') will be shifted downwards in the illustration in Fig. 4. This again results in changes to the intersections between transport mode costs curves. Let D represent distance where intersections between the generalized costs curves for two transport modes are indicated by parameters t, r, and w for the transport

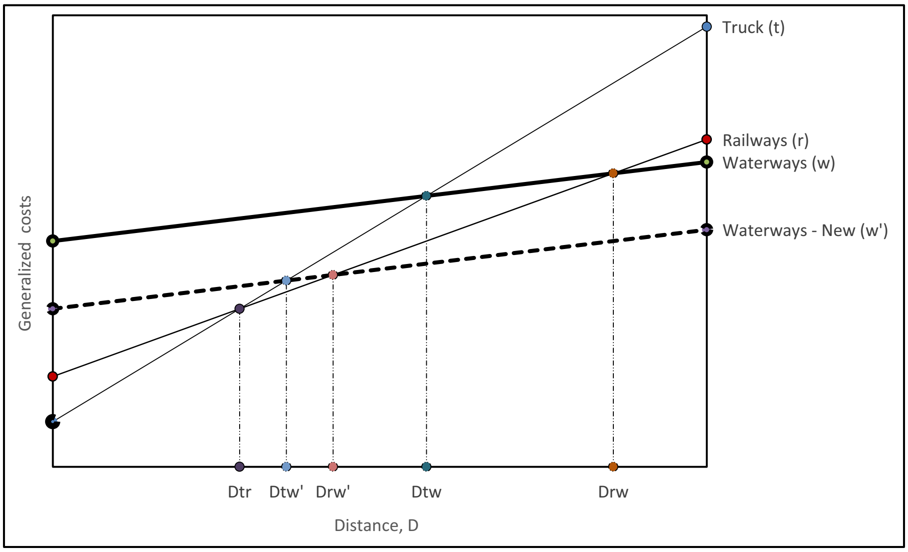


**Fig. 4** Illustration of the relationship between generalized transport costs and transport distance for truck, rail and inland waterways

modes road, railways and waterways respectively. Dtr is the intersection between road and railway costs, which is not influenced by the introduction of improvements for inland waterways. Dtw is the intersection between the cost curves for road transport and inland shipping. This intersection is traditionally at longer distances than Dtw, but by the improved efficiency from autonomous navigation this intersection is reduced to Dtw', meaning that inland shipping can to a larger extent compete with road transport over shorter distances. Drw is the intersection between railway and inland shipping, which is reduced to Drw' after improvements in inland waterways. This means that inland shipping can compete with railways over shorter distances as well. This makes inland shipping a competitive option with the lowest cost over much shorter distances. The slope of generalized transport cost for inland shipping may change in the future, but it is still uncertainty as there is no current evidence on the parameter. An illustration of the generic relationships explained above is shown in Fig. 4 where the preferred transport solution for any distance is represented by the curve indicating the lowest generalized costs.

#### Stakeholder analysis

The reviewed literature also helps explain the relationships between different actors. The relevant actors are positioned on a four-quadrant power-interest matrix. The criteria for identifying them is based on their roles and involvements (Dobrzyński et al. 2015; Schmeer 2000; Kristen 2015; Ackermann and Eden 2011) on autonomous shipping adoption by the inland waterways sector. Local and regional regulatory bodies such as CCNR, CESNI, and UNECE are classified into one category. While the current literature provided an overview of the majority of the stakeholders, some potential future stakeholders are not mentioned. Therefore, in addition to what the literature mentioned, this paper suggests additional stakeholders, such as cargo owners, financial institutions, technological entrepreneurs, and insurance providers. The stakeholder analysis is shown in Fig. 5 below.

This approach is beneficial for policymakers as it allocates resources to significant stakeholders to promote innovation. Shipping companies fall into "The players" category, and they should be engaged with and influenced closely. Based on this analysis, policymakers should focus their efforts on understanding shipping companies. RCC operators, tech-entrepreneurs, shipyards, and classification societies belong to "The subjects" category, and they should be kept informed about the innovation. They can provide valuable insights and inputs due to their high interest in innovation. Cargo owners, financial institutions, terminals and ports, port state control, regulatory bodies, and flag states represent "The context setters". They should not be informed as intensively as the previous two groups, but they must be kept in the loop due to their influence on innovation policy. Lastly, agents and brokers, insurance providers, vessel traffic services, communication providers, and operators are part of "The crowds" category and should be monitored.

## Discussion and conclusion

This paper aims to provide an understanding of autonomous inland shipping from the perspective of the diffusion of innovation theory. The results from a structured literature review (SLR) with PRISMA 2020 guidelines were used to answer the research question, "*Which variables affect the adoption rate of autonomous inland shipping*?". The inclusion of short sea shipping (SSS) studies is based on its nature and further autonomous operation similarities with inland shipping. Most variables affecting the adoption rate are identified from published articles, except for intrapersonal relationships. Although the number of publications on this topic is limited, interest has grown recently. The relative advantages are the most frequently mentioned factors. Lower crew costs, safer and more efficient operations, and attractive working conditions would appeal to actors at the knowledge stage of the innovation-adoption process and the consequences of this new innovation is discussed using the framework of generalized cost. Autonomous shipping

| INTEREST | low | high |
|---|---|---|
| high | **Subjects:** Keep Informed<br>Remote Control Centre (RCC)<br>Tech entrepreneur<br>Shipyards<br>Classification society | **Players:** Engage closely and influence actively<br>Shipping companies |
| low | **Crowds**: Monitor / minimum effort<br>Agents and brokers<br>Insurance<br>Vessel traffic services (VTS)<br>Communication providers<br>Canal and locks operators | **Content setters**: Keep satisfied<br>Cargo owner<br>Financial institutions<br>Terminal operators and ports<br>Port state control<br>Regulatory bodies<br>Flag states |
| | low | high **POWER** |

**Fig. 5** Stakeholders analysis matrix (own elaboration)

addresses the industry's current needs for innovation and improvement. However, the complexity is high, imposing new demands on employees, operational challenges, paradigm shifts, and regulatory barriers. Both trialability and observability are facilitated by regulators and public reporting. The innovation decision is optional, with no local or regional government incentives available. The social system is considered to have strong norms and interconnection, as the industry is saturated, traditional, and has high entry barriers and surplus supply. The structure is identified as decentralized, with no middle change agents. Shipping companies have the most crucial role as they can change the industry from the inside. This paper finds that autonomous shipping is an emerging innovation for the industry, therefore it offers implications for both practice and theory.

First, policymakers' agenda to achieve sustainable transport by increasing the modal share of inland shipping (CCNR 2022; Eurostat Statistics Explained 2023) can be achieved with the introduction of autonomous shipping and supported by policy implementation. A modal shift will be possible in the future with autonomous shipping features in reduced transport service price, lower transport and external costs, and increased subsidies. This would make inland shipping the cheapest transport mode in much shorter distance (Mathisen et al. 2015), as it is shown in the result of generalized cost of transport analysis. Stakeholder analysis result provides an overview of relevance players to make this innovation successful. Policy makers should involve them in collaborative methodology in formulating strategy such as focus group discussions (FGD), collaborative approach, and innovation policy framework.

Second, this paper contributes to the innovation and transport literature. It differs from other literature reviews on autonomous shipping for sea transport (Wiśnicki et al. 2021; Li and Yuen 2022; Ziajka-Poznańska and Montewka 2021; Alamoush et al. 2024a). This paper utilizes diffusion of innovation to identify innovation factors of autonomous shipping for the inland and short sea shipping. This paper addresses some potential research agendas. First, this paper demonstrates the potential of combining the diffusion of innovation framework with a systematic literature review, a method that could apply to another interdisciplinary research as well. Second, this paper introduces an illustration of the costs of changing generalized transport modes with changes in costs and subsidies for autonomous inland shipping. Future research should address the possible modal shift scenarios with real-world data simulation. Furthermore, future research about the operation of inland freight transport should be conducted as other transport modes are also advancing with innovations, such as electric and autonomous trucks. Third, behavioral research about stakeholders' preferences towards autonomous shipping with primary data collection should be conducted to enrich the literature. There is a more recent study shows the integration of stakeholders analysis with other frameworks, such as life cycle analysis (Alamoush et al. 2024b). Fourth, this paper identifies a research gap related to internal communication among actors within social networks of inland shipping. Future research should explain this phenomenon to provide a better understanding of inland shipping dynamics. Fifth, the same methodology can be applied to identify different emerging innovations in transportation. Sixth, future innovation research shall look into different levels of autonomy and extend it to sea transport and Maritime Autonomous Surface Ships (MASS), which is a recent growing research trend (Alamoush et al. 2024a).

It would affect how the innovation is perceived by different players in the sector which resulted in different typology of innovations of autonomous shipping. Lastly, the integration of systematic literature review and innovation theory in this paper should be the foundation for more advanced research in innovation, such as modelling diffusion of innovation and rate of adoption.

This paper is not without a limitation. First, in such a systematic literature review (SLR) approach, there is no primary data collection. The data collection is based on published articles from Scopus and Web of Science datasets. Second, the original application of the Rogers (Bui 2015) diffusion of innovation theory is initially rooted in agricultural research but recently it has been demonstrated that the framework is useful in the maritime transport (Rehmatulla et al. 2015; Karslen et al. 2020; Chica et al. 2023). The DOI theory assumes that agents or adopters use innovation similarly, where in the real world the adoption process is more complex than that. Further research shall address this gap with primary data collection to explain the phenomenon and the dynamic better. Third, this paper addresses the perspective of individual adoption according to Rogers' framework (Rogers 2003), while the adoption of autonomous shipping may involve organizational processes in a shipping company rather than individual's. Further studies should address this limitation by referring to the organizational innovation adoption literature in the maritime industry (Alamoush 2024). Fourth, this paper investigates general level of autonomy while there is a big difference between autonomy level 1 and 3 (CCNR 2018). Lower levels of autonomy may be adopted sooner than higher ones. For example, remote-control operations are already a business practice in Flanders, Belgium. Lastly, the limited amount of available literature also affects the quality of this paper.

**Abbreviations**

| | |
|---|---|
| AVs | Autonomous vehicles |
| AAWA | Advanced autonomous waterborne applications initiative |
| CCNR | Central commission for the navigation of the rhine |
| CESNI | Comité européen pour l'élaboration de standards dans le domaine de navigation intérieure |
| DoI | Diffusion of innovation |
| DVW | De Vlaamse waterweg NV |
| GHGs | Greenhouse gases |
| IMO | International maritime organization |
| IWT | Inland waterways transport |
| MASS | Maritime autonomous surface ship |
| MDK | Maritieme dienstverlening en kust |
| MT | Maritieme toegang |
| MUNIN | Maritime Unmanned Navigation |
| RCC | Remote control centre (RCC) |
| SLR | Systematic literature review |
| STM | Sea traffic management |
| UCSDA | Unmanned cargo ship development alliance |
| VO/O | Vessel owner/operator |
| VTS | Vessel traffic services |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s41072-024-00189-6.

Additional file 1.

Additional file 2.

**Acknowledgements**
An early version of this article was presented at the World Conference on Transport Research (WCTR) 2023 in Montreal, Canada. I thank the attendees for their suggestions on my paper. I also wish to thank the anonymous reviewers of this journal for their constructive feedback on previous versions of my article. Their input has helped me revise this article.

**Authors' contributions**
The solo author is responsible for the overall development of the paper.

**Funding**
Open access funding provided by Nord University. The research leading to these results has received funding from the European Union's Horizon2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No955.768 (MSCA-AUTOBarge). This publication reflects only the authors'view, exempting the European Union from any liability. Project website: http://etn-autobarge.eu/.

**Availability of data and materials**
The datasets for the current study are retrieved from Scopus and Web of Science datasets. All data generated or analyzed during this study are included in Supplementary materials.

## Declarations

**Competing interests**
The authors declare that they have no competing interests.

Received: 25 October 2023 Revised: 29 October 2024 Accepted: 18 November 2024
Published online: 05 December 2024

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## Publisher's Note