Domenighini *Journal of Shipping and Trade* (2024) 9:14
https://doi.org/10.1186/s41072-024-00171-2

Journal of Shipping and Trade

ORIGINAL ARTICLE

Open Access

Autonomous inland navigation: a literature review and extracontractual liability issues

Camilla Domenighini[1*]

*Correspondence:
camilla.domenighini@uantwerpen.be

[1] Faculty of Law, University of Antwerp, Venusstraat 23, 2000 Antwerp, Belgium

Abstract

Pilot tests for (semi-)autonomous transport via inland waterways are already taking place in Belgium and other European countries. However, the full commercial implementation of autonomous inland shipping might be hampered by liability issues. The allocation of liability, especially extracontractual liability, is an important concern for shipowners who want to invest in autonomous barges, and for other ecosystem actors. For this reason, a balanced risk distribution framework could boost the investment decision. A legal analysis of the current laws and regulations is necessary to evaluate whether they can be applied to new autonomous systems. The research approach consists of two steps. First, an in-depth literature review is carried out to determine whether extracontractual liability research has already been conducted and to highlight the gaps in autonomous inland waterways transport studies. Once it is proved that the vast majority of the research focuses on technology, it can be affirmed that there is a need to inquire about extracontractual liability. In the second part, thus, the two international Conventions on liability limitation and collision in inland navigation are examined.

Keywords: Inland waterways transport, Literature review, Extracontractual liability, Autonomous inland shipping, CLNI 2012, Geneva Collision Convention 1960

Introduction

Inland waterways transport (IWT) is recognised to be, in many ways, a sustainable way of transport, all considering the external costs. In particular, IWT presents better results regarding accidents, air and noise pollution, effects on climate, and congestion (Rohács and Simongáti 2007; Al Enezy et al. 2017; Hofbauer and Putz 2020; Sys et al. 2020).

However, IWT represents only 6% of the modal split in the European Union (EU), while the goods transported by road exceed 75% of the total (European Commission, Statistical Office of the European Union 2020). The trend has not changed over the years. Nevertheless, this data must be considered from an infrastructural perspective; in fact, in countries where the inland waterways network is developed, the modal split of IWT reaches 40% (i.e. The Netherlands). The EU has recognised the importance of a modal shift from road hauling to railways and inland waterways transport. With the European Green Deal, the European Commission aims to shift part of the current road-hauled goods to more sustainable inland transport (European Commission, 2019).

The strengthening of sustainable transport as the policy goal underneath this plan must consider which technologies are employed in the various modes. The sustainable character of IWT is increasingly reduced compared to the innovation introduction pace in road transport. Lorries deployed on EU roads are newer than the barges that navigate its waterways. According to Eurostat, 70.905 million vehicles per km were four years old or less, while all the other lorries counted 54.134 million vehicles per km (Eurostat 2022). According to IVR data, between 2017 and 2022, 676 new IWT vessels were built in the Rhine region (Benelux, France, Germany and Switzerland) (IVR 2022). The average life of a barge lasts many decades, around 60 years (Sys et al. 2017). The different life spans of lorries and barges depend, among others, on the cost of the vehicle, the necessity of financing, the second-hand market in and outside the EU, and the time for a complete worn-out.

The implementation of new technologies is considered a *condicio sine qua non* for IWT to remain competitive. This mode of transport stands at a historical crossroads; either it will catch up with innovations or other transport modes will take over its market share, introducing greener, more sustainable and more reliable solutions faster than IWT (Verberght and van Hassel 2019).

The paper aims to understand the state of the art of autonomous IWT studies and to address extracontractual liability issues related to the introduction of autonomous barges.. The first part of the paper relates to the gaps in the autonomous IWT research, and the second addresses the applicability of CLNI 2012 and the Geneva Convention 1960 to autonomous barges. A literature review can help highlight research gaps (Wee and Banister 2016). To address the gaps in the research about autonomous IWT a literature review is conducted through the Scopus database. The choice of keywords aimed to collect a wider range of topics, to assess how the research is distributed across academic fields. To address the extracontractual liability issues the analysis of the two conventions allows to highlight whether their application would produce any legal uncertainty or risk distribution imbalance.

Autonomous inland barges

Among the innovative technologies available on the market, autonomous navigation systems are already a reality, and they are deployed on unmanned and remotely controlled barges in regions where innovative policies, i.e. Flanders in Belgium, allow these experiments to take place on their waterways.

Being a relatively new concept, it is still worth distinguishing between technologies which allow a certain degree of automation of the different phases of transportation and navigation (Autopilot, Trackpilot, and others) and fully autonomous systems. In the last case, the barge is navigated and controlled by AI software able to perform all the operations required for the navigation: propulsion, steering, mooring, avoiding collision, communication with other barges, port authority, lock and bridge operators, understanding the risk in the environment and onboard and act to solve them and assure safety. In this case, humans should not be involved in any decisions, and they may or may not remotely monitor the barge operations. The CCNR has described five different levels of automation (CCNR 2018).

Autonomous barges are expected to have many advantages, such as being greener, faster, safer, more flexible and reliable, adding more capacity and cutting costs in the mid-long term (Verberght 2019). In particular, it allows for better planning of the voyage, which, together with constant speed and automated operations, reduces fuel and time consumption (Verberght and van Hassel 2019). Without humans in the loop, no human errors will cause accidents and fatalities, making navigation safer for (remote) seafarers, passengers and goods. Currently, human errors are causing 80% of incidents (Schreibers et al. 2021), even if this number is debated among scholars (Bačkalov et al. 2021). In the long term, autonomous barges will possibly become cheaper as they allow a cut on crew costs and accountancy costs, the digitalisation of chartering and brokering will reduce freight costs, and safer navigating systems will possibly reduce insurance premiums, although, in the short run, this may not be the case as the insurance cost will follow the capital value of the vessel (Verberght and van Hassel 2019).

Although it is possible to retrofit a barge with autonomous systems, the best results in terms of reliability are offered by newly built barges, in which the design allows the tech provider to outfit sensors and other mechanical parts compatible with the autonomous navigation system. Autonomous barges may combine new generation engines that reduce emissions or implement non-fossil fuel engines; moreover, the hull may be redesigned to cope with drought and low water levels and fit in small waterways (Verberght and van Hassel 2019).

Autonomous barges present interesting perspectives for the sector; however, the implementation does not depend only on the technical feasibility or viable business cases. Firstly, the experimentation and the use of these kinds of systems need to be authorised and regulated by the relevant policy bodies; secondly, the implementation must be accepted by the public, especially given the fact that IWT, more than ocean shipping, is a much closer activity for the people living in countries with inland waterways. Third, the management of risk needs to be addressed. The investments and the transport operations must be safe for the investors and owners, who must be able to insure their risks. The presence of new actors—i.e. technology providers—raises issues about their liability, which may exceed the one generally linked with software developers. The introduction of AI systems may generate gaps in damaged parties' compensation rights, leaving room for liable defendants to get away with responsibility. The allocation of responsibility, traditionally channelled towards the barge owner throughout vicarious liability, may be disrupted given that the crew will be substituted by software, or, on the opposite, action or negligence of independent contractors may still trigger the liability of the owner. The traditional power of barge owners and carriers to limit their liability may also be secured to other parties. Insurance companies, for their part, will be interested to know the liable parties to be able to offer the best cover and determine premiums.

As seen above, the introduction of AI determines uncertainty in the field of liability. Even cornerstones such as fault-based liability might not remain untouched, as scholars are already proposing the application of strict liability.

It is clear that research on this topic is crucial, and many scholars have recognised the need for it (Verberght 2020; Gu and Wallace 2021); however, the research on the topic is limited.

The literature review

To better understand the state of the art on autonomous IWT research, a literature review has been conducted. The work aims to highlight the fields in which the research is more developed and, on the contrary, in which areas gaps are still present. A narrative, also known as traditional, literature review, conducted with the broadest scope possible will help to analyse the current knowledge on the topic of risk distribution in autonomous IWT.

Methodology

The literature review has been conducted with the Scopus database. All the papers will be considered up to the end of August 2022. Sixteen queries have been utilised with different combinations of the words: 'autonomous', 'unmanned', 'inland', 'river', 'ship', 'barge', and 'pusher'. The queries have been searched with the TITLE-ABS-KEY field.Fig. 1 shows the results of the queries.

The initial results based on the automatic research amounted to 447 papers. Thus, they have been filtered based on the content of the title and the abstract (e.g. a paper on autonomous systems used in logistic warehouses to store goods transported by an inland barge would have been excluded or a paper on drones exploited to verify the accuracy of automatic identification systems in rivers), in some cases, e.g. Liu et al. (2022), literature dealing with the maritime environment has been included because of the references explicitly done to the inland waterways navigation. The language used is English, and only English-written papers are considered; this leads to the elimination of five papers written in Chinese (Yang and Xu 2014; Wang et al. 2018a, 2018b; Tian et al. 2021; Wang et al. 2021; Yang et al. 2022). The result obtained counts 220 papers.

Among the group of 220 papers, some publications were recurring multiple times; thus, any duplicates have been deducted. The final count of the review stops at 126 papers. Although the literature review was conducted in August 2022, thus, it represents only the first two-thirds of that year, in the past years there has been a constant growth in the number of papers published on the topic.

The following paragraphs will provide the content of the gathered papers. It shall be noted that for the aim of this literature review, i.e. identify gaps in the research topic, the scope is very broad, collecting research on autonomous IWT from any field of study. Papers published in the five years before this review have been considered (2018–2022 included). Indeed, 2018 does not only represent half of a decade of studies on the topic, but it is also the first year in which the number of papers has exceeded 10.

The results of the review allow to organise them into subjects: technologies for navigation, guidance, control and communication, design and manoeuvrability, human–machine interactions,, maintenance, risk analysis, experiments, economics, exploitation of the technology, and law and regulation. The division in macro subjects is visualised in Fig. 1. At the end, a discussion on the results will be made.

Technologies for navigation, guidance, control and communication

Fully autonomous ships will be equipped with systems able to operate the vessel without the intervention of humans. In the following subsections, technologies

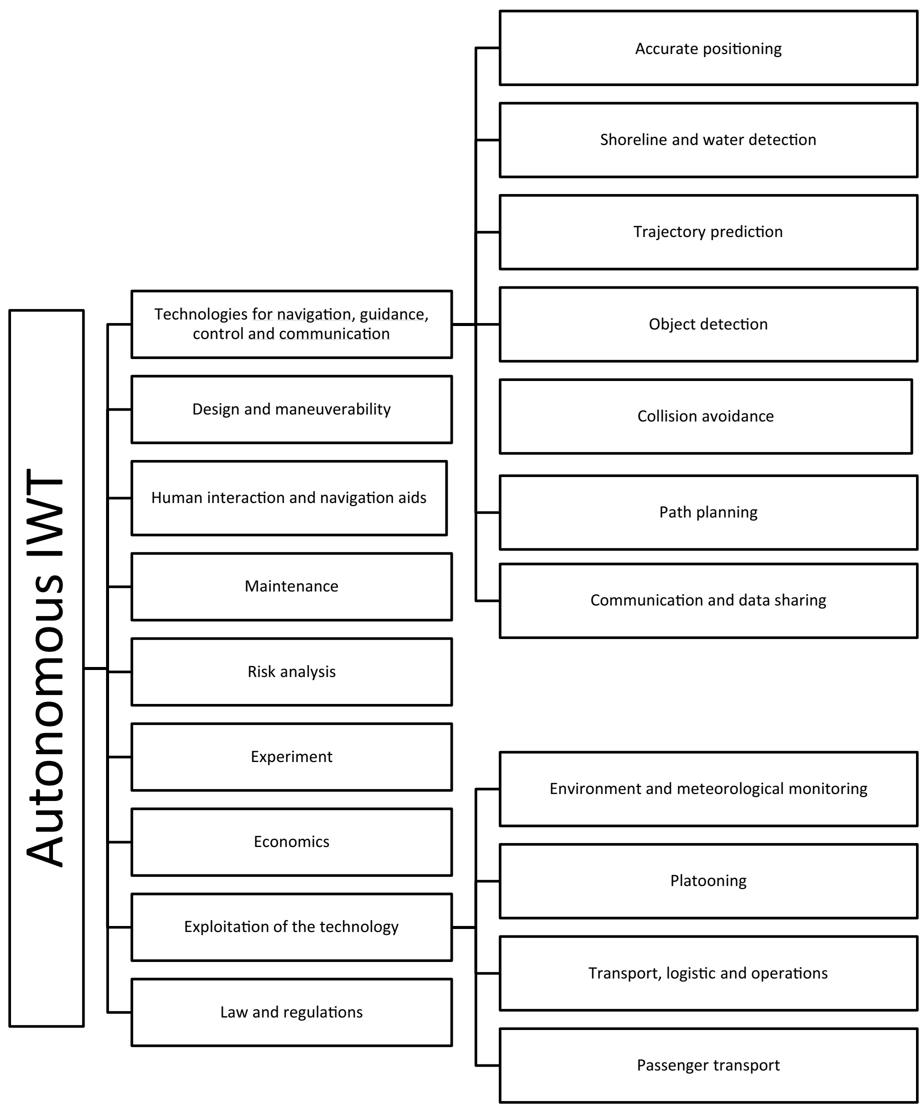

Fig. 1 Literature review subjects. Own composition

developed for the different subsystems that compose an autonomous surface vessel as defined in Schiaretti et al. (2017) will be reviewed. Hinostroza & Guedes Soares (2018) propose a guidance, control and collision avoidance system for operating autonomous surface vehicles in critical navigation conditions. Similarly, an overview of the guidance, navigation and control technology has been presented for an autonomous ferry (Koschorrek et al. 2022). Xiao et al. (2022) designed a multi-mode control system for an unmanned vessel.

More conceptually, Danilin et al. (2021) review two different standard control system structures for unmanned vessels. Conceptual research is also used to understand the feasibility and the benefit of an autonomous ferry line, considering it as a complex system (Karetnikov et al. 2022). Moreover, also Da Silva et al. (2021) and Chen et al. (2019b) elaborate on an unmanned vessel's control function.

Accurate positioning

To allow remote-controlled and autonomous navigation is essential to determine the vessel's position in the most accurate way possible especially in restricted and highly navigated areas, such as ports and inland waterways. The problem of accuracy in the positioning depends on processing complex navigation information, Sikarev et al. (2020) present a model to enhance information security of the full process. Wang et al. (2020) address the problem of highly accurate positioning for urban waterways localisation and control strategies. Alissa et al. (2021) present the findings of using a Network-RTK (NRTK) service to improve the performance of GNSS receivers with accurate positioning. Andryushechkin et al. (2021) share the result of using navigation buoys to communicate with vessels and provide accurate positioning through RTK corrections. Yayla et al. (2020a, 2020b) propose using two satellite navigation systems, Galileo and EGNOS, which provide better results than using GPS only. Also Cueto-Felgueroso et al. (2018) developed solutions based on a receiver that processes EGNOS V3 data.

Shoreline and water detection

Open water detection may be considered the flip side of object detection. However, it is as important as the latter to assure safety during navigation. Plenge-Feidenhans'l & Blanke (2021) use a classification convolutional neural network and combine it into a map to help annotate images, which is needed for machine learning. Also, Gao et al. (2022) research water segmentation, fusing Lidar points and 2D image results. Moreover, Samson (2018) presents the result of a test involving a shoreline detection algorithm. Yin et al. (2022) propose a water shoreline detection approach based on an enhanced Pyramid Scene Parsing Network focusing on training efficiency and its robustness.

Object detection

Safe navigation depends on real-time object detection; multiple algorithms have been analysed and trained to detect, classify, and track objects thanks to a dataset created specifically for inland waterways by Hammedi et al. (2019). To strengthen the awareness system, the authors present a system able to define safe navigation areas and locate and map the environment simultaneously (Hammedi et al. 2022). In another study, the effectiveness and reliability in identifying targets during navigation are analysed; the authors (He et al. 2019) propose a hip target recognition method based on single-shot multi-box detector (SSD) deep learning. Also, the work of Yu et al. (2019) aims at improving ship detection using a Gaussian mixture model (GMM) and a K-means clustering algorithm. Further, the plane of water analysis is used to obtain the accurate orientation of the cameras onboard, which allows a better localisation of objects and obstacles (Qingqing et al. 2019). The data and the safety of the navigation can be improved by modelling a multi-sensory fusion of data derived from lidar and echosounder (Stateczny et al. 2018b).

Collision avoidance

Bahls and Schubert (2021) show the application of a machine learning algorithm based on differentiable programming for the navigation of autonomous river ferries, which can avoid collision with other vessels on their paths. The Collaborative Autonomous Shipping Experiment (CASE) focuses on the possibility of autonomous ships to sail collectively in restricted waterways too, and it tests the autonomous vessels model in challenges about avoiding collision and bypassing other vessels (Haseltalab et al. 2020). Moreover, the dynamic avoidance of objects and path adjusting during navigation are the goals of a navigation control decision-making algorithm with environmental adaptability and learning ability described by Yang et al. (2019). Obstacles avoidance is obtained with data from many sensors, Robinette et al. (2019) provide an evaluation of those sensors based on their effectiveness and practicality in inland waterways. Finally, Pshikhopov and Gurenko (2020) researched the autonomous control of the ship movement using object avoidance methods.

Path planning

One of the characteristics of autonomous barges is path planning, which improves fuel consumption and navigation time. This can be challenging in crowded waters, and with the need to minimise the cost, Yan et al. (2020) research the peculiar navigational necessities of cargo ships and develop a path-planning approach based on anisotropic fast marching. Moreover, Huang and Abel (2022) work on path planning in narrow water channels with an incremental sampling method. The trajectory planning is based on a weighted A*-heuristic. Collision avoidance is also considered with broad- and narrow-phase detection approximating obstacles by convex polygons.

Trajectory prediction

The prediction of future positioning of ships is a key element in navigation in restricted areas, and it also represents one of the solutions to assure navigation safety.Trajectory prediction is calculated with different sensors and modalities, such as “GPS coordinates, radar images, and charts specifying water and land regions” (Dijt and Mettes 2020), in this study, the authors propose a Trajectory Prediction Network exploiting multimodal sensors. Furthermore, the “PREParE SHIPS” project (Hüffmeier et al. 2020) presents a system designed with dynamic models and machine learning that communicate the location data ship2ship and ship2shore. For the same problem, Long Short-Term Memory Network Optimised by Genetic Algorithm is the approach used by Qian et al. (2022). Moreover, Volkova et al. (2021) propose a correction to increase the reliability of path prediction in the proximity of infrastructures using satellite signal. Cheng et al. (2021) deal with the navigation issue of traffic lanes and present a probabilistic decision-making approach based on ship and traffic characteristics. Finally, Wu et al. (2020) present an approach based on fuzzy logic-based intelligent decision-making, which considers the dynamic characteristics of the ship and the traffic. This can be helpful both in the case of navigation support tools and in autonomous navigation.

Communication and data sharing

Ai et al. (2021) address the issue of strengthening the communication system between unmanned inland barges and the shore base stations, such as ports, locks and others, making it reliable, low-cost and energy-efficient. The high cost of satellite communication and the limited battery and CPU resources of an inland vessel requires peculiar solutions different from maritime ones. Thus, the authors propose “an intelligent reflecting surface (IRS)-aided wireless inland ship mobile edge computing (MEC) network architecture". Moreover, situational awareness for autonomous navigation is guaranteed by data collected by Lidar and others that must be shared between vessels. However, the stream of data, especially in case of high distances between the ships, relies on long-range networks, which diminishes the data quality (de Hoog et al. 2022); the authors consider the size reduction using Google Draco and the quality outcomes. In another paper, the inland shore control centre's concept and design are investigated to determine the feasibility of remote control or monitoring unmanned and autonomous vessels (Peeters et al. 2020e).

Design and maneuverability

The introduction of autonomous self-propelled barges also needs to rethink the barge's design. Different design aspects are considered to study the feasibility and limitations of unmanned barges (Peeters et al. 2020b). The design (Peeters et al. 2019) and the hydrodynamical behavior (Peeters et al. 2018; Peeters et al. 2020c) are studied to foster motion control and the manoeuvrability of barges is tested with sea-going ship tests (Peeters et al. 2020d, 2020e). Moreover, Cheng et al. (2019) present a mathematical model for manoeuvring ship motion (MMG model). Moreover, Xu et al. (2020) describe the vessel dynamics with the 3-DOF of Abkowitz model and experiment in a river ecosystem, while Dos Santos Neto et al. (2021) models and identify the dynamics of an autonomous vessel, taking into consideration disturbances and non modelled dynamics. In Peeters et al. (2020a), the authors present the mechanical design of non-conventional thrusters and two models to exploit the data produced. An autonomous vessel with an aerial azimuth propulsion system is proposed by (Da Silva et al. 2021).

Human interaction and navigation aids

Whenever humans remain in the loop in the various degrees of autonomous navigation, human–machine interaction is an important aspect to consider. Liu et al. (2022) provide a literature review on the topic and some discussion on the role of human–machine interaction in areas where full autonomous navigation may be challenging, such as inland waterways. Peeters et al. (2020d, 2020e) test navigation aid systems on an unmanned vessel in inland waterways and propose a path for evaluating their impact.

Maintenance

The monitoring of the communication devices and navigation equipment is important for safe navigation, Karetnikov et al. (2021) present a method and a device to implement the monitoring. Moreover, Abaei et al. (2020) also show a method to predict maintenance schedules for the repair and inspection of components of autonomous ships and increase the reliability of unattended machinery plants.

Risk analysis

Safe navigation depends on predicting dangerous situations, which applies to manned and unmanned ships. However, when the crew implements the risk assessment, this may lead to a wrong decision; according to the authors (Karetnikov and Sazonov 2021), the use of artificial neural networks will help to overcome these issues.

Bolbot et al. (2020) propose a cyber risk assessment method for autonomous inland vessels providing an identified scenarios ranking considering the differences between vessel types and control centres. Furthermore, Bolbot et al. (2021) apply the Hazid process to evaluate the risk of autonomous vessels based on the identification of the hazard, their causes and consequences and their rankings. More than 80 hazardous scenarios were identified for autonomous ships in IWT. Moreover, it is highlighted that reputational and third-parties safety risks are considered highly severe in the IWT environment. Later, Bolbot et al. (2022) developed a mechanism to select risk matrix ratings required to perform the risk assessment of autonomous vessels. The methodology consists of four phases and considers the individual and societal risk acceptance criteria.

An analysis of the potential risks is conducted by Zhao et al. (2021), who look at the potential causes of accidents with a Bayesian-based network training approach: while autonomous vessels will improve safety as there will be crew, at the same time, some concerns arise on how an autonomous system will deal with other kinds of accidents (e.g. fire onboard). Zhang et al. (2019) propose a safety risk analysis based on a Bayesian fuzzy network. The safety risk impact factor framework of unmanned vessels in inland rivers is established based on three aspects: the ship aspect, the environmental aspect, and the management and control aspect. Moreover, to prove the cyber risk of unmanned vessels, G. Danilin et al. (2022) report some accidents that occurred in the previous years, caused by infection with ransomware viruses or to steal data from a military ship or hacker attacks on ship navigation systems. Finally, as collision causes accidents in IWT, the identification and evaluation of collision hazards and the possibility of forecasting the hazardous events are examined by Ma et al. (2018).

Exploitation of the technology

Environment and meteorological monitoring

Autonomous vessels are not only developed and deployed as a means of transport for goods. They are used for environmental and water monitoring (Moulton et al. 2018; Berman et al. 2020; Chensky et al. 2021), to collect marine meteorological measurements (Chen et al. 2019a), to monitor and collect data from wetlands (Odetti et al. 2018), to make hydrological measurements (Da Silva et al. 2021), to map the underwater bed and collect bathymetric data from inland and coastal environment (Sanfilippo et al. 2021; Dohner et al. 2022; Marchel et al. 2020; Mohd Adam et al. 2021) and to perform hydrographic surveys (Stateczny et al. 2018).

Autonomous surface vessels have also been proposed to collect the data related to water inflows of the river for energy purposes, Regina et al. (2021) discuss the positioning the sensors to reduce the error in the measurements. If an autonomous robot is used to collect water quality data that could be affected by a non-accurate trajectory, Simmerman et al. (2021) show in their paper the possibility of using an autonomous surface vehicle to collect the data, reducing deviation from the path planned. Unmanned vessels have been proposed for cleaning of the surface of urban rivers from garbage (Xiao et al. 2022).

Platooning

The technology enabling autonomous vessels is analysed in the literature for vessel train formation, also known as platooning. In all the cases, experiments took place in inland waterways. The issues of path following, speed and collision avoidance have been investigated in the light of a distributed control approach to enable fuel-efficient vessel train formation (Chen et al. 2019b). Research is also done on communication and vessel grouping (Chen et al. 2018).

Meersman et al. (2020) tackle the economic advantages of semi-autonomous vessel train formation. Moreover, platooning was one of the challenges in the CASE experiment (Haseltalab et al. 2020).

Transport, logistics and operation

The introduction of autonomous vessels in densely trafficked waterways requires coordination at the higher level (cloud-shore-ship); for this reason, some scholars (e.g. Hualong et al. 2021) propose an autonomous waterway transportation system which exploits perception, decision-making, control, and learning capabilities to provide transport services. Similarly, Wei et al. (2021) conceptualise and simulate an autonomous waterborne transportation system (including ports, locks, and bridges) made of physical, virtual and logical entities. Moreover, the opportunity for self-learning and organisation of the system potentially improves efficiency and capacity. Wennersberg et al. (2020) believe that an IWT supply chain analysis may help guide stakeholders' choices and implement autonomous vessels.

Passenger transport

Many scholars study IWT autonomous vessels for passenger transport. They present logistic advantages in the case of Bergen, Norway (remote parking terminals, saving significant travel distance and cut the cost of crew facilities in terminals) (Gu and Wallace 2021); notwithstanding the requirement of some shore technological infrastructures, inland ferries represent a promising future in Russia (Karetnikov et al. 2022), and in Germany (Koschorrek et al. 2022). The safe automation of river ferries depends on the state estimation capabilities achieved with a navigation filter that sends feedback to the control loop (Nitsch et al. 2021). Moreover, Reddy et al. (2019) combine autonomous transport with zero-emission ferries as a better option for sustainable urban mobility. The benefits of sustainable ferries for urban mobility are increasing public transport network connectivity, reduced travel distance, and fostering modal shifts towards foot travel and bike riding (Tarkowski and Puzdrakiewicz 2021). Also, the autonomous vessel Roboat II is designed to carry passengers for urban mobility (Wang et al. 2020).

Law and regulations

Bačkalov (2020) reviews technical regulations addressing the safety of inland cargo vessels in Europe for the future implementation of autonomous vessels. The author highlights three barriers that may affect the introduction of autonomous systems in IWT, among which there are rules preventing unmanned or remote-controlled operations and those which derive from the "human-centred" design of the ship. The author outlines the required amendments and proposes some solutions. Also Nzengu et al. (2021) deal with the analysis of regulations for the introduction of autonomous vessels in IWT, firstly the regulatory bodies are identified, and then regulations are checked for amendments or new developments; finally, a strategy is proposed to overcome the barrier and fill the gaps.

Experiment

Tackling the topic of experimentations, some authors provide the parameters that led to the choice of test areas, such as technical requirements and hydrographic characteristics (Karetnikov et al. 2020). The simulation can also be done virtually: Shuo et al. (2018) create a realistic scene visual model and test a program route planning and environmental awareness. Instead, Kracht et al. (2022) describe the design and the building of a high-tech simulator which permits simulative developments and demonstrations of automation functions that may be implemented in fully autonomous vessels in the future.

Economics

Verberght and van Hassel (2019) analyse possible business cases for the IWT sector, and the societal benefit, success and failure factors of autonomous technology are individuated. Two kinds of analysis (system of innovation approach, SIA and Social Cost/Benefit Analysis, SCBA) are carried out.

In the case of semi-autonomous vessels, train formation allows the reduction of the crew. This creates an economic advantage for the following vessels' owners. An additional cost derives from the necessary technology. Depending on different scenarios, the economic benefit can be positive or negative. From a societal perspective, external cost savings should be positive (Meersman et al. 2020).

Discussion

The literature on autonomous inland ships is growing; this indicates that the topic and its challenges, from all perspectives, are recognised as peculiar, and researchers agree on the fact that the research for autonomous sea-going vessels, however proximal and developed it can be, it does not suffice, and the inland waterways require targeted research, for instance due to the traffic in the waterways and the increased risk of collision, the restricted areas for the operation, the water level change, the complex natural and urbanized environment around the waterways.

It is evident from the results described in the literature review that the vast majority of the studies are conducted in the engineering field and concern the technology used on autonomous inland vessels and in their ecosystem.

In some cases, the research on autonomy is already linked with non-fossil fuel kinds of engines, fostering the technological and sustainable twin transition. The fact that very few results were coming from the query containing the word 'barge' or 'pusher' indicates that technical research focuses more on the environment of the operations, the inland waterways, than on the specific kind of vessel, except for ferries.

The literature review shows huge gaps in the autonomous IWT research. For instance, social science research is lacking: for a seamless introduction of autonomous barges it is vital to research human–machine interaction both on board and in the control centre, the training of future workers and the societal acceptance of this new kind of vessel navigating in the proximity of riparian urbanized environment. Additionally, no critical examination of possible externalities of IWT seemed to be considered by current research. Although, some research has been found in the field of economics, many aspects remain uninvestigated from a management perspective (e.g. business models).

Moreover, considering research in law, it should be stressed that although two papers were retrieved in the review, those concern mainly regulations in IWT, it follows from this that research on risk distribution and liability is completely absent. This may be partially explained by the fact that the literature review focused on English pieces of research while it is possible that legal research is conducted in other languages and is not indexed in major databases, such as Scopus, used in the current review. Furthermore, it is also possible that such research is developed in grey literature.

The errors of the systems controlling the ships, the malfunctioning of sensors and machinery providing real-time data to the system (position of the vessel, position of other obstacles in the surroundings) or allowing for predictive modelling (trajectory prediction), the fallacy of data provided by third-party used in navigation (e.g. weather conditions, water depth) or to train the AI systems, the failure in performing autonomous manoeuvring will, in the best scenario, fail to deliver the efficiency performances they are intended to provide. In the worst case, they may, alone or in combination with other factors, provoke accidents during navigation. The inevitable coexistence of autonomous and conventional barges will also pose issues related to the communication between vessels, especially in distress situations. Whenever two barges are following a course which will lead to a collision, every means shall be taken to alert the other ship and avoid the collision, this may involve sounds and lights, an autonomous barge needs to be able to pick up those signals, interpret them correctly and react. At the same time, those may represent a danger for the situational awareness of the autonomous barges as they may interfere with the correct functioning of the onboard sensors. Those incidents will trigger the liability of the shipowner. However, with a recourse action by the shipowners or their insurer with subrogation rights, or in torts by the damaged party, other actors of the ecosystem may be found liable and obliged to compensate the damage, for instance, the technology provider.

It is also worth noting that the majority of the works dedicated to risk analysis focus on the evaluation or the description of hazards during navigation rather than on legal aspects. Only in one case, in Bolbot et al. (2022), liability aspects are mentioned, although only to limit the scope of the presented research and exclude them from the analysis. However, the paper refers also to financial exposure as part of the risk analysis. As the authors report financial consequences derive from ship operation disruption, litigation costs, insurance costs, and fines. Those costs and their repartition depend on which parties are considered and held liable, on whether the damaged party will need to prove the fault, and on whether allegedly liable parties will be able to limit their liability. Thus, legal analysis on risk distribution is at the same time lacking but essential.

This is confirmed by the economics literature. Verberght and van Hassel (2019) refer to liability distribution, together with other legal aspects related to the absence of master and crew onboard, as an important factor in allowing the implementation of autonomous barges.

Extracontractual liability

The literature review has proved that little research has been dedicated to regulation for autonomous IWT (Bačkalov 2020; Nzengu et al. 2021), while research on liability is completely absent. As seen above, autonomous navigating systems may bring imbalances in risk distribution and uncertainties in applying the law. However, investigating the topic, understanding which issues arise, and proposing solutions for a clear and well-balanced liability landscape can boost trust in such technology and help the implementation on a large scale.

Extracontractual or non-contractual liability, also known as tortious civil liability, arises in case of damages to a third party which is not bound to the responsible party with a contract which regulates obligations, rights and consequences in the case of the breach of those obligations. The liability of a carrier towards a cargo interest party for damage to the cargo is contractual as it is based on the breach of the contractual obligation to deliver the goods undamaged, which arises from the contract of transport between the two parties. The damage suffered by a barge which collides with another barge because of the latter's fault will bring forth extracontractual liability claims as no contract exists between the two shipowners.

Collisions in IWT are not isolated events, given the restricted spaces of waterways. Norms and regulations on collision are laid down in national laws; however, a tentative to uniform the rules on the matter has been done by the Convention relating to the unification of certain rules concerning collisions in inland navigation 1960 (Geneva Convention hereinafter).

For the purpose of this paper, it is useful to inquire whether the Convention's provisions would remain applicable to collisions involving autonomous vessels and whether the interpretation of the rules would give rise to uncertainties or an unbalanced distribution of the risk for instance, the possibility for the responsible person to get away with liabilities and leave the damaged party unsatisfied. Legal certainty responds to the need of people and businesses to plan and to act relying on the rules and their application, and to foresee the consequences of their actions and those of third parties. The law and its application, responding to their role of allocating risks, must thus be predictable (see Popelier 2000).

It is important to underline that the Geneva Collision Convention does not apply to all kind of damages that may happen in inland shipping. On the contrary, it does only apply to the case of collision or quasi collision, excluding, for instance, the case of allision (the event of an accident between a barge and an infrastructure), although, sometimes, national laws equate the two events (e.g. the Netherlands). In all the other cases, default tort law will apply. In Europe, extracontractual liability is mostly a fault-based liability. Thus, the commentary and the analysis done for the Geneva Collision Convention may be extended to other kind of accidents, with some limitations, i.e., prohibition of legal presumptions of fault and a claim time limitation of two years. An interesting case is represented by an accident happening during the mooring operations. With the development of the technology, terminals may be equipped with autonomous mooring systems, shifting the mooring operation from the barge to the terminal. This operational disruption may have legal consequences linked with the responsibility of the parties in case of accident and resulting damages. In this case, however, terminal terms and conditions may regulate the liability of the terminal in case of damages, for instance excluding liability or capping it to a limited amount of compensation. The contractual exclusion of liability give rise to two separate issues, the first is if and how those terms and conditions are deemed as accepted and thus applicable and the second is that national law may forbid extensive limitation of liability (e.g. in case of gross negligence or intent) and thus a judge may rule the correspondent clause void. In case there is no agreement on the distribution of liability, tort law will be applicable, and the same considerations done above are relevant.

Any damage to cargo, passengers and their luggage, infrastructures and structures, the environment, and other vessels (and their crew) gives rise to the duty to compensate on the part of the liable party. Maritime shipping is characterized by the peculiar right of the shipowner to limit their liability exposure, which means to cap the compensation for the damage to a limit provided by law, setting up a limitation fund. Those limits are provided by the Convention on Limitation of Liability for Maritime Claims, signed in London in 1976 and amended by the 1996 Protocol (LLMC 1996). In inland shipping, another international treaty provides the same: the Convention on the Limitation of Liability in Inland Navigation (CLNI) was first signed in 1988 and substituted by another version in 2012. Currently, CLNI 2012 establishes the subjects entitled to limit the liability, claims subject to limitation, the conduct which excludes the limitation, the State exclusions, the procedure, the different limitation funds and the limits.

The right to limit liability is an extremely powerful tool for the shipowner's risk management. It sets a limit to the financial liability of the shipowner against all claimants linked with a damaging event, although with some exceptions (Mandaraka-Sheppard 2013). It allows insuring the liability with an underwriter (the Protection and Indemnity Club), which can identify the risks' structure, estimate the cost of its maximum exposure, and offer lower awards. It is argued that an unlimited exposure for the shipowner would lead to extremely high insurance costs or even the denial of a cover (Mandaraka-Sheppard 2013). The extent of risk without a liability cover can be appreciated by thinking of a river cruise ship colliding a rail bridge while a train transporting hazardous material is crossing, culminating in an explosion which kills many passengers, a chemical threat to the water environment, and destruction of the infrastructure.

The liability limitation is a pillar of the maritime ecosystem; it is thus extremely important to assess whether its application remains consistent with the introduction of autonomous vessels, making the risk poolable and whether other actors who will be part of the inland shipping ecosystem will be able to enjoy the same right.

In the next sections, the Strasbourg Convention on the Limitation of Liability in Inland Navigation (CLNI) and the Geneva Collision Convention 1960 will be analysed. The two Conventions do not exhaust the relevant inland shipping regulatory framework, others and different regulations shall be considered in the perspective of autonomous shipping. Technical regulations, for instance, the "European Standard laying down technical requirements for Inland navigation vessels (ES-TRIN 2023) or the "European Standard for River Information Services" (ES-RIS 2023), should be amended to implement autonomous and unmanned navigation on inland waterways. Similarly, other international conventions laying down the standards and the requirements for the transport of dangerous goods, i.e., "European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways" (ADN) would need to be amended in the light of autonomous barges, as much as Waterway Police Regulations. Those regulations set the standards to which the shipowner and other actors are bound ex-ante the damage, and their compliance is evaluated by the court, however, they do not influence the liability regime per se, which is the focus of this paper.

The Strasbourg Convention on the Limitation of Liability in Inland Navigation (CLNI)

Other authors (Nzengu et al. 2021) considered the application of the Strasbourg Convention on the Limitation of Liability in Inland Navigation (CLNI) to be unproblematic "regardless of the level of automation". The CLNI entitles the (commercial) vessel owner and salvors to limit their liability in case of:

(a) "claims in respect of loss of life or personal injury or loss of or damage to property (including damage to harbour works, basins, waterways, locks, weirs, bridges and aids to navigation) occurring on board or in direct connection with the operation of the vessel or with salvage operations, and consequential loss resulting therefrom;
(b) claims in respect of loss resulting from delay in the carriage of cargo, passengers or their luggage;
(c) claims in respect of other loss resulting from infringement of rights other than contractual rights and occurring in direct connection with the operation of the vessel or with salvage or assistance operations;
(d) claims in respect of the raising, removal, destruction or the rendering harmless of a vessel which is sunk, wrecked, stranded or abandoned, including anything that is or has been on board the vessel;
(e) claims in respect of the removal, destruction or rendering harmless of the cargo of the vessel;
(f) claims of a person other than the person liable in respect of measures taken in order to avert or minimise loss for which the person liable may limit his liability in accordance with this Convention, and further loss caused by such measures."

The limitation covers contractual and extracontractual liability, regardless of the liability's basis. Article 1 defines the term "vessel owner", which shall be understood as the owner, the hirer or the charterer and the operator of the vessel. Moreover, any person for whom the vessel owner or the salvor is vicariously liable, e.g., an employee of the shipowner or the salvor, because of their employment relationship, has the right to limit their liability in case a claim is brought against them (art. 1.3). The same limit applies to liability insurers (art. 1.5). Vessel owners are entitled to avail themselves of the limitation also in claims brought against the vessel (art. 1.3). In the case of autonomous shipping, it is necessary to assess the role of new actors who provide the AI algorithm for autonomous navigation, which can be defined as "technology providers". It is possible to imagine that the latter may be a target for third parties' claims, i.e. the damaged party, seeking restoration of their loss in case of accidents. Technology providers may be picked out instead of the barge owner because the claimants rely on the assumption that the defendant does not have the right to limit. Moreover, a tech company may be considered the one with the deep pockets compared to a barge owner. It is crucial to understand if the interested parties can sue the tech provider and if the latter would be able to limit its liability under the Strasbourg Convention, either as operator of the vessel (art. 1.2.a) or as a person for whom the vessel owner is responsible (art. 1.3).

Considering the first option, the Convention does not provide any definition of operator, nor does the LLMC 1976, which could be considered as the source of inspiration for the CLNI1988 and CLNI2012. The interpretation, thus, will depend on national law. Whether the technology provider is understood to be the operator of the vessel will depend on whether the decision will consider the physical control of the vessel, or, for instance, the economic control of it. As different business models may appear on the scene following the disruptive effect of autonomous barges, it will most likely be a case-by-case decision (Arda 2023). Considering the latter case, two interpretations are possible, a restrictive one, according to which only parties for which the owner is vicariously liable under national law can limit, and a broader one which enlarge the number of possible actors, for instance the ship repairer, for whom the shipowner is liable in case of seaworthiness of the vessel (see Griggs et al. 2005, p.13). This decision is for the judge to make.

The tech providers may opt to introduce an indemnity clause in their contract with the barge owners to protect themselves from any litigation cost and the compensation for the damages. Additionally, they may invoke the application of a "*Himalaya*" clause if contained in the transport contract in case the claim in tort is brought by the cargo interest. This clause extents to independent contractors, servants and agents the exceptions and limitations to which the carrier is entitled. Similarly, if the contract of carriage is subjected to CMNI, and the technology provider is recognised as an agent of the carrier, they will be able to avail themselves of the same limits and exonerations of the carrier according to article 17 CMNI.

More complex is the interpretation of Article 4, which presents the conduct that would bar the right to limit, i.e. conditions under which the person limiting its financial liability is not allowed to do so because the damage is provoked with intent or recklessness by the liable party rather than with negligence. The article states, "A person liable shall not be entitled to limit his liability if it is proved that the loss resulted from his *personal* act or omission, committed with the *intent* to cause such loss, or *recklessly* and *with knowledge* that such loss would *probably* result". This provision imposes a double condition for the exclusion of the limitation right. The losses should result from a *personal* act or omission, and they should either be intentional, or the person shall be aware that there is a probability for the loss to happen and act in that way with disregard for the risk.

Although intent does not cause interpretation issues, for the interpretation of 'recklessness' national courts may adopt different tests which varies from country to country. For instance it can be helpful to look at some German caselaw. The wording of article 5b of the Binnenschiffahrtsgesetz—BinSchG is identical to article 4 of the CLNI2012 (and 1988). In both cases, the standard is twofold, as said earlier.

German courts have interpreted this as an "intentional immoral conduct", which must be at the same time intentional and represent "deliberate gross negligence" (see par. II.2.a

250 Z—2/92—Court of Appeal of the Central Commission for the Navigation of the Rhine). In another case (OLG Nürnberg, 30.03.2017, Az. 9 U 243/14 BSch), the court held the defendant liable because he "crassly disregarded the safety interests of third parties because he deliberately disregarded a fundamental and obvious duty of care. […], anyone who, as a responsible skipper, fails to take such elementary precautions in this situation is acting in the knowledge that the absence of such precautions may result in damage." (par. 24). Recklessness is a "particularly serious breaches of duty" derivate by a "blatantly disregard of the safety interests" in case of dangers that "must be obvious to everyone". Moreover, the judge explains that the awareness of the probability of the occurrence cannot be assumed in the concept of recklessness. However, it is enough "that the risk of the occurrence of damage is obvious" or even a low probability but "not completely insignificant" and "statistically relevant", thus it is not required a probability that exceeds 50% in the person's view (Par. 8–9). The same considerations were previously done also in OLG Stuttgart, 20.08.2010—3 U 60/10.

Differently, in the Netherlands a definition of recklessness with knowledge is borrowed by road transport caselaw (Philip Morris v. Van der Graaf and Cigna v. Overbeek), and requires that "the acting person knows the risk inherent in his act and is aware that the chance that this risk will manifest itself is considerably greater than the chance that this will not happen, yet all this does not restrain him from the act". The standard requires a subjective test. It is not sufficient to prove the recklessness that the person—whose action must be their own—ought to have known about the risk and that it was considerable, but that the person had the knowledge and the awareness that the risk realization was greater than its non-realization. The party wishing to break the limitation of liability of the shipowner or any other person entitled to the limitation must prove actual knowledge and awareness. As authors have observed (Dean and Clack 2020; Soyer 2020; Soyer and Tettenborn 2021) commenting on the identical wording of art. 4 of the LLMC 1996 (after all, LLMC 1976 was the model of CLNI 1988), the recklessness test represents a challenge in case of autonomous ships. The limit is virtually impossible to break, according to Soyer (2020), even when software updates would not be uploaded, as the proof of the act or omission is for the damaged party to be given, which may not have access to the source of the evidences or incur in prohibitive expenses to analyse them.

From a different perspective, the same issue is tackled by Viljanen (2021), who argues about the enormous amount of data that an autonomous vessel will collect and analyse. Maintenance predictions and insights provided by the system may help prove the knowledge that the loss would probably have resulted.

Moreover, in case the liable person is identified in the tech company, it is arguable whether an act or omission is 'personal'; an error in the coding by an employee would difficulty pass the test, but what about the company praxis of hiring untrained personnel to remotely supervise the autonomous vessel? Or install defective sensors on the barge? If the responsible person is the vessel owner would be indeed difficult to prove the knowledge of the probable result of any action or omission, given the highly sophisticated technology involved. In case the "knowledge that such loss would probably result" is an objective test—they should have known it, being irrelevant whether they knew or not—it may be easier to prove it against the tech provider than the barge owner, considering the higher level of knowledge expected from technology professionals.

Finally, the scope of application is set out in article 15. Concerning this article, the wording of the last sentence of the first paragraph shall be revised, or the interpretation shall be broadened. As some scholars have rightly pointed out (Soyer and Tettenborn 2021), salvage in the era of autonomous systems is likely to happen on land. For example, the salvage can be rendered by a shore control centre or a software company. The wording of article 15.1.b does not create any problem for the described perspective, however, in the case in which the salvage or assistance service is rendered to a sea-going ship in inland waterways, only a salvor from an inland vessel and not a land-based service would be entitled to limit their liability under CLNI 2012, and LLMC may possibly apply (Table 1).

Moreover, art. 14.1 CLNI prevents the instigation of any other proceeding in any other courts of CLNI member states by any person entitled to claim after a fund has been constituted within a competent court. This ban is extended to all the states bound by the Brussels I Regulation (Tournaye 2013). Thus, setting up a limitation fund has a strong channelling effect, barring any other jurisdictions and avoiding multiple litigation, i.e., if the shipowner, or any other party entitled to limit—before a claim is brought before any other judge—sets up a limitation fund in a court that has competence to hear the case, then claimants will not be able to ask for compensation linked to the damage in dispute in any other tribunal. The shipowner may have more than one choice in selecting the jurisdiction where to constitute the fund and choose the most favourable, while further harmonization can prevent forum shopping. In the next section, a similar examination will be carried out for the Geneva Collision Convention 1960.

Geneva Collision Convention 1960

The Geneva Convention 1960 governs the compensation for damages caused to vessels or people and objects onboard in case of collision (art. 1.1) and even in the case collision has not occurred (quasi-collision), but damages have resulted from a *manoeuvre* (or the failure on doing so) or noncompliance with regulations. Thus, the Convention does not apply to damages provoked by allision, that is, the wrongful contact with infrastructure, such as bridges, berths, locks or structures in the waterways, e.g. fish ponds. Moreover, the Convention is applicable in case of collision between two inland vessels, even if the event occurs in maritime waters, as long as those are the national waters of a Member state. On the other hand, whenever a sea-going

Table 1 Difference in allowing liability limitation for salvage in case of inland vessel or sea-going ship in CLNI

15.1.b "Salvage or assistance services had been rendered along one of the said waterways to a vessel in danger or to the cargo of such a vessel."	Allow limitation of liability for salvage from land
15.1. Last paragraph. "This Convention shall also apply to the limitation of liability of a salvor rendering salvage or assistance services *from an inland navigation vessel* to a sea-going vessel in danger along one of the said waterways or in respect of the cargo of such a vessel."	Do not allow for liability limitation for salvage from land

vessel is involved in a collision, without regard to whatever waters the event took place in (inland waterways or sea), the International Convention for the Unification of Certain Rules of Law with Respect to Collision between Vessels 1910 (Collision Convention hereinafter) will apply.

The first question to be answered is whether the Convention would apply to autonomous vessel. Although autonomous vessels should be considered as vessel—whereas doubts arise—the broad spectrum of appliances or plants contained in the definition of "vessel" for the scope of the Geneva Convention should clear any hesitation in considering the Treaty applicable to autonomous vessels. Moreover, not applying the Geneva Convention to autonomous barges in countries that have ratified the agreement would lead to claims which will not be time-barred after two years (art. 7), but will follow the general law time bar, which varies from country to country. This will create uncertainties, especially when multiple barges are involved in a collision. It is easy to imagine the event of a collision provoked by two barges, one of which is autonomous (A) and the other manned (B), which causes damage to a third vessel (C). If vessel C brings an action against A and B three years after the event, B will rightly see the claim dismissed because it is time-barred, while A will be found liable. Inasmuch as a short time bar was set to foster the businesses assuring certainty, this perspective alone will create huge treatment inequalities between shipowners and eventually inhibit the introduction of autonomous barges.

Pursuant to art. 2, the basis of liability is fault, and legal presumptions of fault are forbidden, i.e., a rule of law that states that a certain fact should be assumed as negligence. It is up to the damaged party(ies) to prove the vessel's fault and seek compensation for the damages. The Convention does not provide for a definition of fault of the vessel. Fault is a legal concept that has different degrees and different tests; thus, the interpretation of this provision may differ in courts from country to country (see, for example, the works of Hartenstein (2020), Smeele (2020), and Stevens (2020)). In particular, the first (Hartenstein 2020) discusses the applicability of the Geneva Convention to remotely controlled or autonomous vessels. The author focuses on the concept of the vessel and the fault of the vessel under the Convention and under German law; while remotely controlled barges should not give rise to problems, the question is more complex for autonomous systems; according to the author, this strives for an autonomous and uniform definition of fault. In the Netherlands, in the landmark case De Toekomst v. Casuele, 2001, the Dutch Supreme court defined the fault of the vessel as the fault of a crew member, of a person acting in the service of the vessel or the cargo, and a hidden defect of the vessel (Stevens 2020). In this case, a remote controller may, without particular problems, be considered at the service of the vessel, while a negligent software engineer is unlikely to be considered at the service of the vessel if its development work was concluded by the navigation time. A different approach was taken by the Belgian legislator, who decided to interpret the fault of the vessel directly in the text of the law, in this way article 2.7.2.4 of the Belgian Maritime Code define the fault of the vessel as fault of the crew members. This very restrictive approach leaves no room to consider the negligence of the technology provider as a trigger for the liability under the collision regime.

Some authors (Soyer 2020; Collin 2021; Solvang 2021) argued for the application of strict liability for the shipowner in the case of autonomous vessels scholars supporting strict liability argue that the liable party could escape fault-based liability and leave victims without proper compensation for the damages suffered. In fact, the damaged party has the burden of proving the vessel's fault. Such proof may be complex to provide, given the complex system involved and issues related to transparency, interpretability, and explainability, and the high cost of expert witnesses. A strict liability system does not require the proof of fault, making the shipowner liable for damage provoked by the autonomous barge in any circumstances. However, strict liability in maritime law is generally connected with the transport of dangerous goods (The International Convention on Civil Liability for Bunker Oil Pollution Damage, 2001, the HNS convention, the Convention on Civil Liability for Damage Caused during Carriage of Dangerous Goods by Road, Rail and Inland Navigation Vessels 1989). It is a policy decision to deem transport by autonomous barges as risky activity per se, which would be counterintuitive, especially because autonomous barges are expected to be safer than manned ones. A strict liability system could be eased with a number of exoneration grounds, or a fault liability system could be aggravate with a reversal of the burden of proof. Any of these options goes against the provision of art 2.1 and will require a special law instrument for autonomous barges. Thus, under the current framework will not be possible, nor the installation of an autonomous navigation system might represent a presumption of fault.

As much as it has been done for traditional navigation, courts will determine case by case what accounts for fault of an autonomous vessel. The failure to upload the updates of the system, not implementing up-to-date cybersecurity measures, and installing different and incompatible systems against the technology provider's instructions may seem clear examples of the shipowner's fault or fault for which people he is responsible for may incur in.

Furthermore, there is a need for regulations for autonomous navigating systems on waterways. Would navigation that deviates from current navigation rules be considered negligent even if, in general, it would be possible for an autonomous barge to perform it thanks to its sensors and technology? Or entering a waterway expressly said to be "at one's own risk"?

However, implementing technologies such as artificial intelligence and machine learning leads to new problems. If, for the fault of the master, the shipowner would have been held liable for vicarious liability, would it be the same for the "fault" of an algorithm? Nevertheless, the question more probable is: can an algorithm be at fault? Although this possibility has been dismissed because fault is a characteristic of humans (Tettenborn 2020; Røsæg 2021), it is also true that at a certain point, it may be needed to deal with decisions taken by a state-of-the-art navigating system, acting incomprehensibly and causing a collision.

Particularly relevant to the topic is paragraph 2, article 2 of the Geneva Convention. It reads, "if the damage is accidental, if it is due to force majeure, or if its *causes cannot be determined*, it shall be borne by the person suffering it". The application of the *res perito domino* rule is foreseen in the case of fortuitous accidents and force majeure or in the case of inscrutable collision. The doctrine is divided on what should account for force majeure and accident. According to some legal scholars force majeure events or accidents must be external (Ripert 1922; Berlingieri 2014) a sudden failure of the autonomous system could not be considered a force majeure event, similarly, a cyber-attack provoking the collision to the system cannot be deemed as an event unavoidable or unexpected with due diligence in the context of autonomous shipping. However, different opinion is upheld by other scholars (Rodière 1972; Waldstein et al. 2007; De Decker 2015). Accordingly, the unexpected breaking of machinery onboard—e.g. not caused by lack of maintenance—resulting in a collision should be considered accidental and thus not trigger any liability on the colliding vessel. Similarly, assuming this interpretation, the proof that the collision was caused by a defect in the autonomous system which was not discoverable using due diligence would prevent the fault of the shipowner.

The third condition is the case in which no fault can be proved. The wording "if its *causes cannot be determined*" is slightly different from the 1910 Collision Convention, which, in article 2, reads: "if the collision is accidental, if it is caused by force majeure or if the *cause of the collision is left in doubt*, the damages are borne by those who have suffered them", however, they are considered equivalent. According to the Travaux Préparatoires of the 1910 Collision Convention (International Maritime Committee 1997), it incorporates the concept of inscrutable fault or "abordage douteux". Abordage douteux is the remaining category whenever a faulty collision or an accidental collision is not proved (Rodière 1972), in the Travaux Préparatoires is defined as follows: "Inscrutable accident, means that fault causing the collision is not established against either party." (p. 7) although it is said, in the Travaux Preparatoires, to derive from the north American doctrine according to which "Inscrutable fault exists when the court finds a general atmosphere of fault, but is unable to attribute it to either party" (Johnson 1975). However, the explicitation of this case in art. 2.2 of the Convention shall be traced in the intention to harmonise the consequences of such collisions, the application of the res perito domino rule. Before the 1910 Convention, some countries used to distribute equally the damages when either the fault or the accident was not proved. From the standpoint of autonomous shipping, this rule does not significantly contribute beyond what it has already been discussed, i.e. the claimant must prove the fault to obtain compensation.

Finally, the Geneva Convention channels the liability to the vessel (i.e. for the pilot's fault, art. 5); however, it is not specified against whom the claim shall be brought, whether it is the registered shipowner, the bareboat charterer or another actor. In this case, nothing stands before the possibility for the victim to sue the tech provider of an autonomous barge; this will be interesting as, if the defendant wants to rely on the liability limitation, they would need to qualify themselves as one of the categories allowed to do so.

Conclusion

Autonomous inland shipping is approaching, while experiments are already carried out, research continues to develop and important questions arises from a legal perspective in view of a complete operational implementation of autonomous barges.

This work aimed at assessing the status of current research, defining the areas in which is more developed and identify gaps in the literature. Moreover, a systematic classical literature review on autonomous IWT was missing.

The review has been conducted with Scopus, with 16 different combinations of keywords (unmanned, autonomous, river, inland, ship, vessel, barge, pusher); the results have been filtered by language, only papers in English have been considered, and titles and abstracts have been preliminarily skimmed to assure the consistency of the topic. The focus was made on the papers published in the last five years, and the literature review is updated to August 2022. Afterwards, the papers were collected on macro topics and subjects, and the result was analysed. First, it must be highlighted that literature targeting exclusively autonomous IWT exists, and it has constantly been growing. Second,, the vast majority of the research is conducted on the technological part; some risk analysis pieces were retrieved, while outputs from other fields, such as law, economics, and social studies are lacking. Thus, huge possibilities to investigate the topic are open for scholars.

In the second part of this paper, a contribution to fill those gaps is presented. Although autonomous vessels are expected to reduce the number of accidents, the possibility of damages cannot be excluded. For this reason, an analysis of the legal framework is necessary to understand whether the current legal instruments will remain applicable and whether any disruption in the risk distribution is expectable. Thus, extracontractual liability issues have been addressed considering the two main international Conventions on this subject: CLNI 2012 and the Geneva Collision Convention 1960.

The results of this analysis show that the two conventions will remain applicable to autonomous vessels. Moreover, as new actors join the ecosystem and may be held liable for the damage provoked by the autonomous vessel, the question of who would be able to limit its liability arises and, consequently, which behaviours would bar the limitation right or whether this exclusion would become impossible. Concerning the subjective scope of CLNI2012, it has been shown that the technology provider could bar its liability only if identified with the operator or a person for which the shipowner is responsible. It will be left to national courts to ascertain this qualification. Nevertheless, the technology provider could manage the risk linked with a claim by the damaged party by contracting an indemnity with the shipowner. With regard to the possibility of breaking the liability limits, it has been shown that different countries apply different standards in interpreting the elements of the conduct (the recklessness and the knowledge). It has been argued for more uniformity to avoid forum shopping and uncertainty.

Furthermore, the Geneva Collision Convention was considered. Given the shorter time bar granted by the collision law and the broad understanding of a vessel in the definition, autonomous vessel should be subjected to the same regime. As the fault of the vessel is central in collision liability and the convention does not provide any definition, it is vital to look at national laws or the caselaw, in the present work it has been shown that under the definition given by Dutch courts the fault of the technology provider may trigger the liability of the shipowner, while under the restrictive definition of Belgian law this will not be possible. Also, the concept of fault in case of collision leaves room for interpretation by national courts. In general, strict(er) liability system(s) for autonomous barges under the Geneva Convention would be impossible.

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that under the definition given by Dutch courts the fault of the technology provider may trigger the liability of the shipowner, while under the restrictive definition of Belgian law this will not be possible. Also, the concept of fault in case of collision leaves room for interpretation by national courts. In general, strict(er) liability system(s) for autonomous barges under the Geneva Convention would be impossible.

More research is required to evaluate the full picture of extracontractual liability for autonomous IWT; in particular, national laws need to be scrutinised, and the solutions that can be offered under such systems need to be drafted to understand whether and where bottlenecks lie and to propose solutions which will allow seamless implementation of autonomous barges.

Abbreviations

CCNR	Central Commission for the Navigation on the Rhine
CLNI	Convention of the limitation of liability in inland navigation
CMNI	Budapest convention on the contract for the carriage of goods by inland waterway
EGNOS	European Geostationary Navigation Overlay Service
EU	European Union
GNSS	Global navigation satellite system
GPS	Global positioning system
IWT	Inland waterways transport
LLMC	Convention on Limitation of Liability for Maritime Claims
OLG	German Higher Regional Court
RTK	Real-time kinematic positioning

Acknowledgements
The author wishes to thank Prof. Wouter Verheyen, Prof. Christa Sys, Prof. Edwin van Hassel, Prof. Marta K. Kołacz and the anonymous reviewers for their advices in writing this work.

Author contributions
CD conceived, designed the study and wrote the draft.

Funding
Open access funding provided by The Hong Kong Polytechnic University This research is funded by the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement No. 955768.

Availability of data and materials
Not applicable.

Declarations

Competing interests
The author declares that she has no competing interests.

Received: 2 October 2023 Revised: 13 February 2024 Accepted: 12 April 2024
Published online: 28 April 2024

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