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Legal challenges regarding autonomous shipping in inland waters

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Preface

This master's thesis is the closing piece of six inspiring years at Ghent University. I started this journey with a master in Criminological Sciences where I developed a critical view on the world and expanded my research abilities. I then chose for a completely different path and enrolled in the Master of Science in Maritime Science. During this one-year course we were submerged in the maritime world and had the opportunity to learn new subjects outside our comfort zone. Not only did this master expand my horizon and broadened my knowledge, it also brought me in contact with so many interesting people and new friends

This master's dissertation will combine my criminological background and the new knowledge I acquired this year. It joins maritime regulations and new evolutions regarding autonomous shipping in *The legal challenges regarding autonomous shipping in inland waters*. I would like to thank my supervisor Evert Lataire and assessor Maxim Candries for the detailed feedback and useful tips during this process, Ann-Sofie Pauwelyn for the additional information regarding Belgian rules and regulations, Louis-Robert Cool for the information regarding autonomous shipping projects in Belgian inland waters and Kristof Olyslager for the additional insights in the insurance world of autonomous vessels.

I would also like to thank my loving parents for giving me the opportunity of following the Maritime Science program and giving me the much-needed support during these nine intensive months. Lastly, I would like to thank my boyfriend and my wonderful classmates for the laughter and joy they brought this year.

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An-Sofie Obrie

List of abbreviations

AAB	Autonomy Assisted Bridge
AAWA	Advanced Autonomous Waterborne Applications Initiative
ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
AMOS	Autonomous Marine Operations and Systems
BIMCO	Baltic and International Maritime Organization
BSC	Belgian Shipping Code
CEVNI	European Code for Inland Waterways
CLNI	Convention on the Limitation of Liability in Inland Navigation
CMNI	Budapest Convention
COLREGS	International Regulations for Preventing Collisions at Sea
CUS	Continuously Unmanned Ship
DNT	Dynamic Navigation Tasks
DNV-GL	Det-Norske Veritas and Germanischer Lloyd
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation vessels
FSA	Formal Safety Assessment
GBS	Global-based standards
GDPR	General Data Protection Regulations
H2H	Hull to Hull
HSBA	Hamburg School of Business Administration
ICS	International Chamber of Shipping
ILO	International Labour Organization
IMO	International Maritime Organization
InCom	Technical Commission concerned with inland waterways and ports
ISF	International Shipping Federation
KRISO	Korea Research Institute of Ship & Ocean Engineering
LLMC	Convention on the Limitation of Liability for Maritime Claims
LNG	Liquid natural gas
LR	Lloyd’s Register
MASS	Maritime Autonomous Surface Ship

MOL	Mitsui O.S.K. Lines
MSC	Maritime Safety Committee
MUNIN	Maritime Unmanned Navigation Through Intelligence in Networks
ODD	Operational Design Domain
P&I	Protection and Indemnity insurance
PIANC	The World Association for Waterborne Transport Infrastructure
PKI	Public Key Infrastructure
PUB	Periodically Unmanned Bridge
PUS	Periodically Unmanned Ship
SCC	Shore Control Centre
SPOC	Single Point of Contact
UNECE	United National Economic Commission for Europe
USV	Unmanned Surface Vessels
VTS	Vessel Traffic Services

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1. Introduction

Ever since the beginning of mankind, humans have been looking for ways to make life easier, more efficient, and more productive. Time is money. From the invention of the wheel, the hot air balloon and the steam engine to cars, planes, and the hyperloop, we have tried to save time by inventing faster modes of transport and tried to save money by optimising their design. Automation is the next logical step in this process. Autonomous trains have been around since the eighties, today's cars are already capable of autonomous steering, braking, and adjusting to speed limits, full self-driving software is being released and autonomous busses have been in use since 2020.

The shipping industry is going through the same process and is looking into autonomous vessels with already several projects being tested. Due to the international character of shipping, a legal framework regarding autonomous shipping is still being researched and is yet to be drafted. Individual countries have launched their own initiatives, some of which will be discussed in the following sections. This thesis will examine the challenges confronting autonomous shipping within the Belgian inland waterways. To frame the scope of the problem, international conventions will be discussed as well, however they are not the main objective.

First, I will define the concept of autonomous shipping as there are different levels of autonomy and thus a variety of definitions (section 1.1). I will then sketch the (short) history of autonomous shipping, why was it researched, what is the necessity etc. (section 2). Thirdly the current Belgian legal framework will be discussed. Due to the complex structure of the Belgian State, I will make a distinction between Flemish, Walloon and federal rules and regulations (section 3). The core of this thesis will be the legal challenges regarding autonomous shipping in inland waterways. How can autonomous shipping comply with the rules and regulations regarding crew requirements, technical requirements, and police regulations? This will be done by gap analysis (section 4). Since autonomous shipping is relatively new and is still being tested, I will also discuss a few (Belgian) projects that are currently being tested in the Flemish waterways (section 5). This will be followed by an overview of the other challenges autonomous shipping is facing (section 6). The thesis will be concluded with some recommendations (section 7) and a discussion (section 8).

1.1. Definitions

In order to discuss autonomous shipping, the concepts 'autonomous' and 'unmanned' must first be defined as they are often ambiguous and used as synonyms when used for ships (Porathe et al., 2018, pp. 417-425). The bridge might be unmanned for certain periods of time, but this doesn't mean that there is no crew on board to take control when needed. A ship can also be remotely controlled from a Shore Control Center (SCC) via a communication link. Is this vessel unmanned or autonomous? There is also uncertainty as to what functions 'unmanned' or 'autonomous' applies.

In short, 'Autonomous' implies the ship's capability of making decisions independently from humans, this does not mean no people are present. 'Unmanned' means there are no humans present on the ship's bridge to perform operations; maintenance crews, passengers etc. can still be on board (Dremliuga & Mohd Rusli, 2020; Renault, 2018; Rødseth & Nordahl, 2017). For the purpose of this thesis, we will focus on defining the term 'autonomous'.

1.1.1. International Maritime Organization

To have a truly autonomous ship all shipboard function must have the option to function at some degree of autonomy, this degree might be different for every function (IMO, 2021). The International Maritime Organization (IMO) distinguishes four degrees of autonomy. These four degrees, as described by the IMO in their scoping exercise regarding maritime autonomous surface ships (MASS), depend on the level of on-board manning, and concern the division of tasks between automated systems and humans in complex decision-making processes. Increased autonomy is therefore linked to the removal of human involvement (Ringbom, 2019).

1. *Automated processes and decision support*: With this level of autonomy there are still seafarers on board. Some operations are automated and sometimes unsupervised, but seafarers are ready to take over control when necessary (Kim et al., 2020). This can also be referred to as the *Autonomy Assisted Bridge* (ABB) or the *Continuously manned bridge* (Rødseth & Nordahl, 2017).
2. *Remotely controlled ship with seafarers on board*: This ship is controlled and operated form another location, seafarers are still on board to take over operations (Kim et al., 2020). Another term for this kind of autonomy is the *Periodically Unmanned Bridge* (PUB) (Rødseth & Nordahl, 2017).

3. *Remotely controlled ship without seafarers on board*: The ship is fully controlled and operated from another location without seafarers on board ready to take control (Kim et al., 2021). This type of autonomy is also called the *Periodically Unmanned Ship* (PUS) (Rødseth & Nordahl, 2017).
4. *Fully autonomous ship:* This ship is capable of making decisions and can take action without human interference (IMO, 2021). This kind of autonomy is also known as the *Continuously Unmanned Ship* (CUS) (Rødseth & Nordahl, 2017).

The IMO makes a distinction between levels of autonomy (degree one and four) and levels of manning (degree two and three) but emphasises that the organization by degree of autonomy does not represent a hierarchical order. During a single voyage different levels of autonomy may be applied (IMO, 2021; Porathe et al., 2018, pp. 417-425).

1.1.2. Scholars

Not only the IMO has tackled the issue of characterizing autonomy in ships. Rødseth and Nordahl (2017) proposed to characterize 'autonomy' along three axes to reflect the ambiguity of the concept. The first axis describes the *complexity* of the operation, captured in the Operational Design Domain (ODD). Traffic, weather conditions, sailing route, water depth etc. all determine the complexity of the shipping operation. The second axis is the *level of manning* as the bridge can be manned constantly but can also function totally autonomous without crew or remote monitoring. The last axis is the *operational autonomy* and describes how the operational tasks are divided between humans and machines. The operational autonomy can be zero when all tasks require human intervention or there can be total operational autonomy when tasks are completely handled by automation systems. The operational autonomy is captured by the Dynamic Navigation Tasks (DNT) (Porathe et al., 2018).

1. *Operator controlled*: The DNT is fully handled by the operator. Systems can provide support when making decisions and can take over control in a very limited way. For example, when a ship is using the auto pilot, it is operator controlled. Most ships today are operator controlled.
2. *Automatic*: The ship can operate without human intervention for a specific function and situation. An operator will be requested by the ship if the operational parameters should deviate from the expectations of the pre-programmed sequence. The SCC or bridge crew is always available if action is needed.

3. *Partly autonomous*: The ship can perform certain DNT autonomously. For example, a ship can transit open sea in normal weather conditions. This type of autonomy can be used to have a periodically unmanned bridge.
4. *Constrained autonomous*: The ship can operate autonomously for almost all DNT as there is a predefined selection of options for solving commonly encountered problems like collision avoidance. The operation system has clear limits to what action it can take and to what extent. If the system cannot solve the problem within these constraints a human operator will be called to intervene. In all other cases, the system is expected to operate by itself.
5. *Fully autonomous*: The ship can handle all DNT by itself as there will be no SCC or bridge personnel to intervene. According to Rødseth and Nordahl (2017), this is a realistic alternative for operations over short distances.

To avoid tunnel vision and work within a broader scope, the definition of the Maritime Safety Committee (MSC) will be used to define MASS. They define MASS as "a ship, which to a varying degree, can operate independent from human interaction" (Shiokari & Ota, 2019). Even though this definition describes maritime ships, it will be used for inland vessels as well.

2. Autonomous vessels: an overview

This part will first discuss the history of (autonomous) vessels starting with a timeline of early revolutionary changes regarding shipping in general. Then the focus will shift to autonomous vessels, how they came to exist, important progresses and why the concept was initially researched.

2.1. Technological evolution

Technology to improve shipping has been evolving rapidly since the 18th century. During the First Industrial Revolution a mechanized power was introduced with vessels being propelled by steam whilst using coal as fuel (Kim et al., 2020). The Second Industrial revolution began with the invention of the diesel engines, these engines soon replaced steam engines on ships (McNally, 2022). Vessels became more reliable, and efficiency increased by using oil as a new fuel (Kim et al., 2020). The Third Industrial Revolution, starting in the 1970s, was marked by the internet-digital revolution. Ships were now being computerized which was the beginning of the journey to autonomous ships (Kim et al., 2020). In the last ten years, research and tests regarding autonomous shipping have boomed (see Figure 1) and technology is proceeding towards a shipping 4.0, using high quality data in the process of automation (Roberts, 2018; Rødseth & Berre, 2018).

Although there was a lot of resistance towards the implementation of innovative technology, the future of shipping will be controlled by new methods and machinery. The current technical advancements in shipping have already improved navigation, safety and communication and have successfully contributed to efficient and reliable maritime transport. As new technologies come into existence, it will create opportunities but also issues in other sectors like infrastructure, logistics, safety etc. (SHM, 2018). These will be discussed later on in the paper.

2.2. Timeline of key events

The concept of autonomous ships was first introduced by Rolf Schonknecht during the 70's in his book "Ships and shipping of tomorrow" (Roberts, 2018). Schonknecht stated that future captains and engineers would control and operate their vessels from an onshore building using computers (Iorliam, 2019). An innovative idea that would encourage researchers to improve the maritime industry and that is now commonly known as remote controlled vessels.

The first effect of this idea of autonomous ships soon became clear. From 1982 to 1988 Japan implemented their Intelligent Ship Project (Hasegawa, 2004; Rødseth, 2019). The goal was to develop highly reliable plants and automatic operations systems to improve the maritime field (Roberts, 2018). These systems would be able to operate the ship without the presence of crew on board and would receive support from shore. In 1988 the Japanese managed to simulate all these systems on a computer.

In July 2011 Korea started a project led by the Korea Research Institute of Ship & Ocean Engineering (KRISO). The project focussed on the development of autonomous Unmanned Surface Vessels (USV) for surveillance and research purposes (Roberts, 2018). The goal was to design technology that was environmentally friendly, could respond to maritime accidents and traffic and could be used in underwater robotics. The final product resulting from this project is called ARAGON, an unmanned surface vessel tasked with ocean observation and sea surveillance (Son & Kim, 2019).

In September 2012 the European Union started their own project called "Maritime Unmanned Navigation Through Intelligence in Networks" (MUNIN). The goal was to assess the feasibility of unmanned ships in terms of technology, economics, and legislation. The ships were autonomous in the sense that the vessel was guided by automated on-board decision-making systems but controlled by an operator on the ship (MUNIN, 2016).

In 2013 Det-Norske Veritas and Germanischer Lloyd (DNV-GL), now DNV, the world's largest classification society, initiated a new concept known as ReVolt (Roberts, 2018). It is a revolutionary concept for zero emission, battery powered unmanned ships designed for short voyages. The project ended in 2018 but a scale model is still being used for testing autonomy and collision avoidance (DNV, n.d.).

In that same year Norway created Autonomous Marine Operations and Systems (AMOS), a centre for autonomous marine operations. (Robert, 2018). The researchers at AMOS are working together to create a multidisciplinary and world-leading centre for autonomous marine operations and control systems. The focus lies with developing intelligent ships and autonomous unmanned vehicles for operations in extreme environments (NTNU AMOS, n.d.).

Two years later Rolls-Royce Commercial Marine, now part of Kongsberg, started an initiative called the "Advanced Autonomous Waterborne Applications Initiative" (AAWA) (Jonioinen, 2016; Roberts, 2018). The initiative researched the different challenges related to autonomous shipping operations, particularly environmentally friendly autonomous and remote operation systems for navigation, onboard operation, and machinery. AAWA aims to produce a design for the next generation of advanced ship solutions by bringing together universities, engineers, equipment manufacturers etc. (AAWA, 2016).

In February 2016 Lloyd's Register (LR) deployed a guidance concerning cyber-enabled systems on ships, this guidance was later updated in 2017 (Roberts, 2018). This document states the procedure to assess cyber-enabled systems, systems formerly controlled by the ship's crew, onboard a vessel classed by LR. (LR, 2017).

Three months after this development Mitsui O.S.K. Lines (MOL) launched a project in cooperation with the Japanese Government to develop a technological concept for an autonomous ocean transport system (Roberts, 2018). They will analyse the strengths of each company and organisation involved to create a vessel that is equipped to provide safe, reliable, and efficient ocean transport (MOL, 2017).

In the following months Rolls-Royce demonstrated the world's first remotely operated commercial vessel, Kongsberg launched its Hull to Hull (H2H) project addressing safe navigation, Korea successfully tested their first unmanned ship (ARAGON II) on a real sea trial and the first cyber-enabled ship (The MV COSCO Shipping Aries) was officially noted by LR (Roberts, 2018).

In April 2018 the world's first autonomous shipping company was born, Wilhelmsen and Kongsberg joined forces and created Massterly (Roberts, 2018). The goal of Massterly is "to offer a complete value chain for autonomous vessels, from design and development to control systems, logistic services and vessel operations" (Midtbø, 2018).

One month later the IMO decided to investigate the safety, security, and environmental impact of MASS, and by doing so taking its first steps to address autonomous ships (Roberts, 2018). The technical body of the IMO, the MSC, started a regulatory scoping exercise including a preliminary definition of MASS and the degrees of autonomy (IMO, 2018)

On September 4th, 2018, DNV-GL released ship guidelines for autonomous and remotely operated ships (Roberts, 2018). Increased automation has the potential to enhance the safety, efficiency, and environmental performance of ships, but to do so it needs a set of standards to make sure new technologies are implemented in a safe manner (Chambers, 2018). These developments show the importance of guidelines, a problem that will be emphasized later in this thesis.

It is also important to mention the Yara Birkeland. This fully electric and autonomous zero-emission container vessel is the first of its kind and was designed to reduce NOx and CO_2 emissions. The environmentally friendly autonomous ship was developed as a part of the Norwegian government's Maritime opportunities – Blue Growth – for a Green Future strategy (Munim, 2019). It is estimated that the Yara Birkeland could replace 40 000 journeys done by diesel trucks annually and will therefor reduce CO_2 emissions by 750 tons (Kristoffersen, 2020). The ship was announced in 2017 and took its first trip on November 18, 2021 (Midtbø, 2018; Yara International, n.d.). The Birkeland will be put in circulation in 2022 starting a two-year trial to become certified as the first autonomous fully electric vessel (Yara International, n.d.).

Lastly, a very recent project, Project Mahi, was finished. Several engineers have joined forces to develop, build and launch an unmanned autonomous vessel powered by solar energy that could cross the Atlantic Ocean. The vessel was built to collect atmospheric and oceanographic data and send this data to the creators via satellite connection. The vessel, Mahi 2, has recently (March 2022) reached Martinique making it the first autonomous vessel to cross the Atlantic Ocean using nothing but solar power (Project Mahi, 2022).

This section listed key developments regarding autonomous vessels and clearly shows the rapid increase in the interest in automation in the past ten years. It also depicts Norway to be one of the frontrunners when it comes to developing the technology needed to automate or remotely control vessel operations.

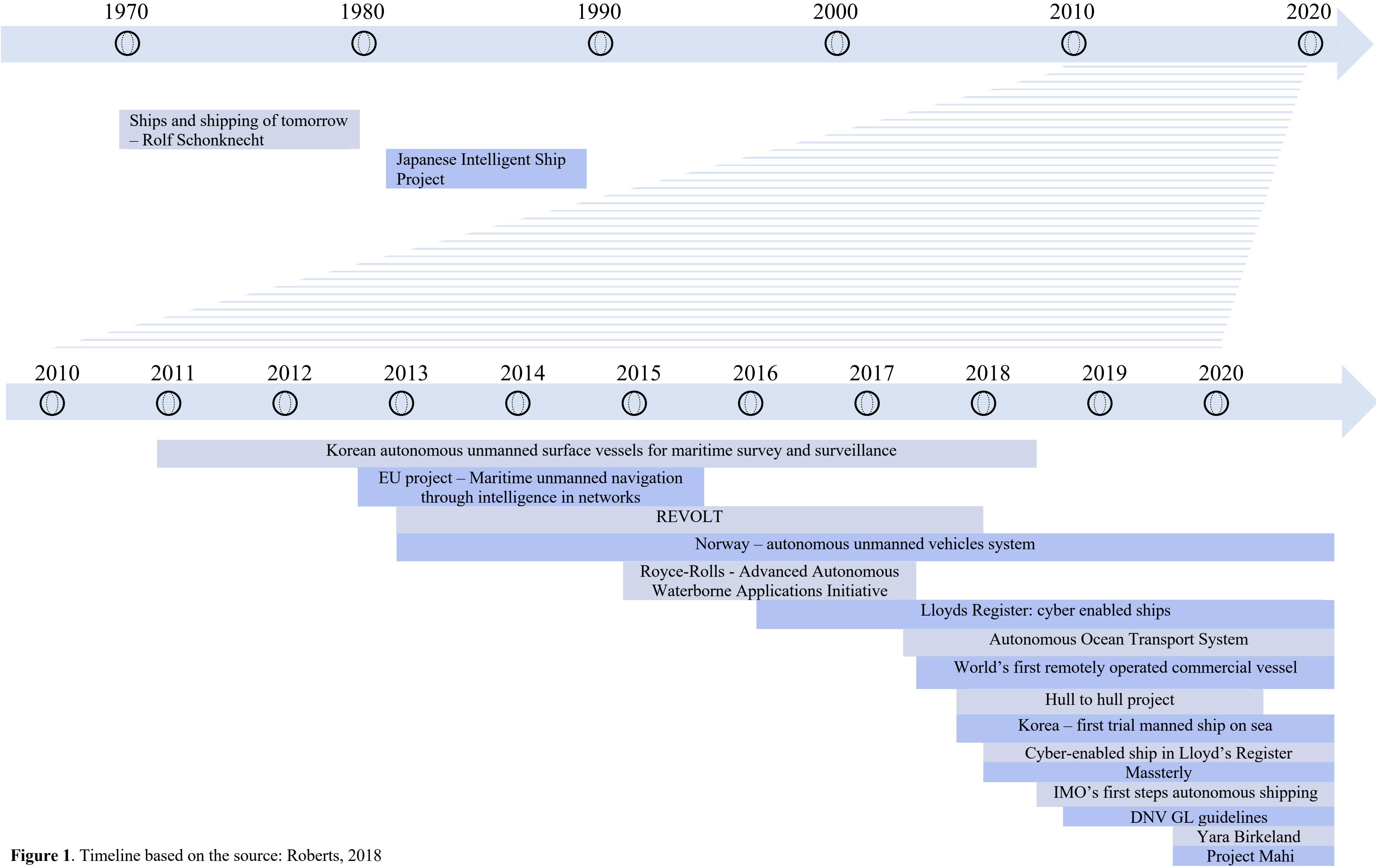

Figure 1. Timeline based on the source: Roberts, 2018

2.3. The need for autonomous vessels

There are four main reasons why the concept of autonomous shipping is being considered and investigated (Kim et al., 2020). The need for better crew working environment onboard and the risk of a shortage of seafarers and skippers in the future, increasing the safety onboard, emission reduction and reduction of transport cost (Porathe et al., 2014).

2.3.1. Work environment

The shipping industry isn't an attractive work environment for young people, which will eventually result in a shortage of seafarers and skippers. This concern was studied by the IMO, the Baltic and International Maritime Council (BIMCO) and the International Shipping Federation (ISF) and resulted in a report that stated that the industry will face a tightening labour market in the future, especially for officers. BIMCO predicts a potential shortage of almost 150 000 officers by 2025 (Petersen, 2016).

A more recent report by BIMCO and the International Chamber of Shipping (ICS) slightly adjusts these numbers. There will be a need for an additional 90 000 officers by 2026 to be able to continuously man the current world merchant fleet. The industry needs to invest in increased training and recruitment levels as the demand keeps growing (Srinivasan, 2021).

Autonomous vessels will be equipped with systems and technology allowing the ship to self-steer, detect obstacles and act on the sensor-based input. This innovative equipment will take over a large part of the tasks now performed by crew and could potentially decrease the number of seafarers needed on board, depending on the type of shipping. However, as long as autonomous vessels are not introduced in commercial shipping, it is not clear how much of the shortage of seafarers the technology can compensate (Komianos, 2018).

Inland shipping has built up a shortage of skippers over the last few years. This has caused smaller ships to disappear resulting in smaller inland waterways not being used. These issues have caused a reversed model shift of cargo being transported by road causing congestion instead of using the inland waterways. The Flemish Waterway nv is now focussing on adding new profiles to reduce this shortage, as well as on autonomous shipping research (De Vlaamse Waterweg, n.d.). Smart ships will replace the skippers that are needed but are not available and will create new jobs in SCCs.

Smart ships with lower manning and a partial monitoring from SCC could be implemented rather quickly in inland waters. However, other aspects need to be considered, there still needs to be a back-up crew and the negative social effect on longer voyages must not be underestimated. Digitalization has made it possible to decrease the crew to such a minimum that it might become harmful over time (Hult et al, 2019).

2.3.2. Increased safety

According to a study by Oxford University on British data from 1976 to 2002, the job of a seafarer is ranked as being the second most dangerous occupation in Britain, the first being a fisherman (Roberts & Marlow, 2005). Most accidents happen due to occupational hazards like carrying heavy gear and falling of a platform, slips and trips and a hazardous environment. Removing crew from these situations would be a safety benefit itself (Porathe et al., 2018).

Shipping itself seems to be very safe and is becoming safer every year. In the year 1980, 225 ships were totally lost, this number declined to 150 in 1996 and eventually reached an all-time low in 2019 with 48 lost vessels (Porathe et al., 2018; Allianz, 2021). This means that the number of total losses has dropped 50% in the last 10 years (Allianz, 2021). Porathe et al. (2018) state that the large decline in shipping accidents has to do with the increase in the use of autonomous systems and automation. Automation addresses human shortcomings like fatigue, attention span, information overload and normality bias (Burmeister et al., 2014; Schreibers et al., 2021).

Research shows that 70-90% of inland navigation accidents worldwide are caused by human errors (Schreibers et al., 2021). This is one of the strongest arguments for the need of autonomous shipping as replacing crew in regular navigation tasks would be beneficial for the safety of the ship (Bačkalov et al., 2021). Ships are highly dependent on the competence of skippers; removing them will eventually reduce shipping accidents, but this removal needs to be compensated by additional safety-by-design measures (Endrina et al., 2019).

On the one hand there are the incidents that are caused by humans and that can be avoided by automation, on the other hand there are the accidents that are now being avoided by human intervention but would happen when no crew is onboard. Automation might be a solution but will also create new types of accidents (Porathe et al., 2018), resulting in a difficult balance.

2.3.3. Reduction of emission

Scientific knowledge regarding the dimension of the environmental impact related to shipping is growing over time (Ng & Song, 2010). Most recent numbers show that more than 90% of world trade is transported across the oceans by 90 000 marine vessels (Oceana, n.d.). Most of these ships use fossil fuels producing carbon dioxide emissions and contributing to climate change and acidification of the oceans. More than 3% of the worldwide greenhouse gas emissions can be linked to seagoing vessels (Yale Climate Connections, 2021). Several environmental groups have therefor been advocating for stricter regulations regarding shipping emissions (Oceana, n.d.). In the last decade measures were taken by the IMO in the form of the Energy Efficiency Design Index and the Ship Energy Efficiency Management Plan, in the context of the Greenhouse Gas Strategy (Bengtsson et al., 2012; Youd, 2021).

The reduction of ship pollution and emission has become more demanding than ever with the introduction of low- or zero-carbon alternative fuels and maximization of energy efficiency (Kim et al., 2017; 2020). Slow steaming and the use of alternative fuels, liquid natural gas (LNG), hydrogen and even solar panels can help the industry achieve this reduction (Youd, 2021).

Autonomous shipping can contribute the most in the reduction of the environmental impact of shipping. Electric powered autonomous ships will emit zero CO_2 and NOx and thus have a direct impact on the emissions form shipping (Yara International, n.d.). Ultra- slow steaming, slowing down the speed of the ship to lower the fuel consumption, will become a possibility as it would be difficult with a full crew onboard. Longer operations and a bigger crew would translate in higher labour costs making it an expensive endeavour. The downside is that slow steaming can only be used in situations where speed is not a factor, thus for non-time sensitive cargo (Anteroinen, 2015; Ventikos & Louzis, 2021). Also, by shifting cargo from road to sea transport the CO_2 and NOx emissions from road transport can be heavily reduced. A modal shift like that can improve road safety, reduce congestion, and mitigate noise pollution in the cities (Munim, 2019). The main reason to shift to autonomous shipping is that it creates the possibility of slow steaming without increasing crew costs and thus improves fuel efficiency which contributes enormously to the reduction of shipping emissions (Kretschmann et al., 2017). Overall, it was found that increasing the number of autonomous ships in the fleet could reduce the emission with 37-64% depending on the route (Liu et al., 2022).

2.3.4. Cost reduction

Unmanned autonomous shipping is seen as a key element for the sustainable shipping industry of the future. This does not imply that autonomous ships will always be the superior choice for ship owners as they look at profitability (Kretschmann et al., 2017). All of the above-mentioned considerations have a cost but will also result in profit. The cost of operating a ship can be divided in three categories: the operational costs, voyage costs and capital costs (Stopford, 2008, pp. 217-268).

The operating costs are the expenses to keep the ship operating, mostly including maintenance costs and crew, which contribute to 20% of the total cost (Ziajka-Poznańska & Montewka, 2021) and up to 30% in inland shipping (K. Olyslager, pers. com., 2022, April 5). The operating cost differ for every ship depending on flag, the type of ship, the age etc. The cost saving potential for the operating cost lies in the crew wages and crew related costs. On a fully automated ship, there will be no crew on board so no wages will need to be paid. There is no crew living on board so there is no need for food, medicine, safety equipment etc. However, an autonomous ship does require shore and port-based services as there is a need for a SCC and maintenance will be conducted in a port. It is an expensive investment but will make a difference on the long term as removal of crew infrastructure will increase cargo capacity and make for smaller and lighter vessels. (Hogg & Ghosh, 2016; Kretschmann et al., 2017; Cross & Meadow, 2017).

The voyage costs are the costs directly associated with the use of the vessel for a particular journey, these include the costs for loading and unloading the ship, port costs, fuel etc. This is the highest cost making up 53% of the total cost, depending largely on the fuel price. (Stopford, 2008, pp. 217-268; Kretschmann et al., 2017; Ziajka-Poznańska & Montewka, 2021). The reduced fuel consumption will primarily be caused by a lower air resistance, lighter vessels, and the removal of the hotel system on board. It is estimated that fuel consumption will be reduced with 6 to15% (Arnsdorf, 2014; Jokioinen, 2016; Kretschmann et al., 2017).

The capital costs are related to the purchase of the ship thus the production costs, regular payments, the interest, and redemption. (Kretschmann et al., 2017). These costs are 36% of the total cost (Ziajka-Poznańska & Montewka, 2021). In the case of the capital costs there will be a delicate balance between the compulsory systems of conventional ships not being required anymore (hotel system, bridge…) and the required autonomous ship technology. The material and production cost of building the autonomous vessel will be lowered with a minimum of 5% if there is no need for a deck house and hotel systems. The autonomous vessel needs the technology and enhanced communication systems, this will again increase the cost. Based on results of the MUNIN project, the costs will increase with a minimum of 5%, which makes it look like a break-even situation (Kretschmann et al, 2017).

Taking into consideration the best scenario where there is a reduced crew and increased fuel efficiency, autonomous ships will have a positive impact in the profitability of shipping companies. However, most research doesn't take into account the cost of insurance, cyber security and emergency arrival of the crew on board (Ziajka-Poznańska & Montewka, 2021).

2.4. Autonomous vessels on inland waters

It is safe to say the above-mentioned reasons to invest in autonomous shipping are applicable to inland shipping as well. According to the Flemish Waterway nv (n.d.) autonomous vessels could have a large impact on inland waterway transport. Autonomous shipping will increase the efficiency of transport on inland waterways, it will absorb the shortage of skippers and add new job profiles, it will create new business opportunities and flows of goods, and it will have a considerable impact on emission and help realise the European Green Deal.

The Belgian government has estimated a shortage of 6000 skippers for inland vessels by 2030. This shortage could be addressed by autonomous shipping (L-R. Cool[1], personal communication, 2022, March 9). SCC could replace skippers on board, it can expand operational time and will significantly increase the operational efficiency. One ship could gain up to 500 working hours per year using autonomous technology (Seafar, n.d.).

Testing autonomous vessels in inland water gives the benefit of a semi-controlled environment. Sailing is highly influenced by environmental occurrences such as wind, waves, and water conditions, all of which are relatively limited in inland waters (Devaraju et al., 2018; van Capelle et al., 2018, pp. 106-123). Systems like the autonomous navigation might not work in situations with harsh weather and high waves which results in an alert to the SCC. The SCC would then have to take over control and take the navigational measures the autonomous vessel

[1] *Louis-Robert Cool* is the CEO of Seafar, a company that supports and operates automated vessels from a SCC. The vessels are integrated with a Seafar Control System and are operated by a licensed captain. Seafar is the first company in the world to realize commercial automated shipping.

could not, causing delays and unnecessary manned navigation (Burmeister et al., 2015; Chakraborty, 2021). This will not be an issue in inland waters.

Autonomous shipping is taking huge steps forward, however there is a big challenge that needs to be overcome before the technology can be implemented worldwide. Legally, autonomous shipping is still prohibited (Pauwelyn & Liégeois, 2019). In Flanders, tests with unmanned shipping are already taking place to identify gaps in legislation. A project was launched in West-Flanders with an unmanned water truck and barge transport from Diksmuide to Oostende. Other autonomous shipping projects will be discussed in the section ‘Belgian Projects’ (INE, 2019).

2.4.1. PIANC Report

The World Association for Waterborne Transport Infrastructure (PIANC) is a high-ranking association which makes reports regarding the design, development, and maintenance of ports waterways, marinas, and coastal areas. They provide the shipping community with guidance, technical advice, and recommendation. In March 2022 the PIANC Technical Commission concerned with inland waterways and ports (InCom) published report n° 210 regarding smart shipping on inland waterways (PIANC, 2022).

Before the report is discussed, we must emphasize that smart shipping and autonomous shipping are not the same (see section 5.1). Smart shipping is broader as it does not only focus on a smart vessel (autonomous ship), but also on smart traffic management and infrastructure, smart travel and transport and smart regulations and facilitation. Only the provisions regarding the vessel and regulations fall within the scope of this paper.

The report begins by defining the scope of the document and lists the smart shipping projects in Europe, the United States of America and China, three of them will be discussed in section 5. The projects are divided according to focus: technology development, policy development and functional testing. The Seafar project (see 5.2) focusses on functional testing, Autoship (see 5.3) researches all three elements and Smart Shipping (see 5.1) examines policy development and gaps.

The biggest concern is the interaction of autonomous ships with infrastructure and other ships. Even though smart shipping is believed to increase safety, sustainability, efficiency and economic performance, most projects are not able to test this due to the very high safety level that needs to be guaranteed and legislation that forbids them to test in real-life situations.

Except in Flanders, the lack of regulations reflecting the different levels of autonomy is a real problem which hinders the progress that could be made in smart shipping. In the Netherlands, projects can only apply for a temporary permit and in Germany testing is only allowed as long as all conditions regarding regulations are met and the required crew is on board. In China Smart Shipping projects are only allowed on a case-by-case basis. The biggest issue is that testing is difficult without a regulatory framework, but one can only develop a decent regulatory framework when there are enough test results to use as a base. The legal challenges identified in this document are the lack of legal framework, General Data Protection Regulations (GDPR) and insurance. The elements regarding framework and insurance will be further discussed in the next sections.

The report states that there is a lack of investment form the government side. The market is small and very specific, so it is hard for companies to find investors who are willing to take a risk and donate resources for R&D. Companies need to rely on the government, but smart shipping is not high on the political agenda in most countries. The government should also create a (temporary) framework allowing vessels to sail without or with a reduced crew. There are many legal gaps that can only be identified by testing these vessels and collecting data. Another issue is the fragmentation of the existing framework, something that will be addressed when discussing the different Belgian regions. Furthermore, it is unclear how liability will work when an accident occurs, an uncertaintywhich is holding companies back to take risks. Another problem reported by the PIANC document is the use of data and the lack thereof, which can be brought back to the lack of legal framework. Technology is another obstacle, although the different projects show that there has been huge progress in this area in the past few years. The report states that the technology is not mature enough to use in real life situations. The rest of the issues relate to infrastructure, the current locks, societal problems, the lack of skill in the labor force and the sector characteristics.

3. Legal framework

This section will list the legal framework applicable to inland shipping by (conventional) vessels (barges etc.) in Belgium. The relevant laws and conventions in force in relation to shipping casualties, cargo claims, and passenger claims will be summed up and later explained. The location of the incident, the type of vessel and the persons involved determine the applicable rules (Kegels, 2021). The scope of application and legal challenges regarding these rules and regulations will be discussed in section 4 'Legal challenges'.

3.1. International framework

In case of an incident/accident (collision, grounding, major casualty etc.) involving inland vessels, these are the key international provisions that will impact the interested parties.

In 1910 the International Convention for the unification of Certain Rules of Law with respect to Collision between Vessels (later: 1910 Collision Convention[2]) was concluded at the Brussels Maritime Conference and was later ratified by most major sea-faring nations (Parks, 1982). Later, in 1952 the International Convention on Certain Rules concerning Civil Jurisdiction in Matters of Collision (later: 1952 Brussels Civil Jurisdiction Convention[3]) was approved. After that the International Regulations for Preventing Collisions at sea (later: COLREGS[4]) were installed to recognize traffic separation schemes. In 1962 the European Code for Inland Waterways (later: CEVNI[5]) was established to bundle existing traffic regulations of the United National Economic Commission for Europe (later: UNECE) member states. In 1989 the International Convention on Salvage (later: Salvage convention[6]) was concluded governing marine salvage. In 2000 the Budapest Convention (later: CMNI[7]) was established for the carriage of goods in inland waterways, together with the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (later: ADN[8]). In 2012 the

[2] The International Convention for the Unification of Certain Rules of Law with respect to Collisions between Vessels, Brussels, 23rd September 1910

[3] The International Convention on Certain Rules concerning Civil Jurisdiction in Matters of Collision, Brussels, 11th May 1952

[4] The International Regulations for Preventing Collisions at Sea, London, 20th October 1972

[5] European Code for Inland Waterways, 1962

[6] The International Convention on Salvage, London, 28th April 1989

[7] Budapest Convention on the Contract for the Carriage of goods by Inland Waterway, Budapest, 3rd October 2000

[8] European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways, Geneva, May 26th 2000

Convention on the Limitation of Liability in Inland Navigation (later: CLNI[9]) was introduced to limit the liability of shipowners in inland navigation. Five years later the European Standards laying down Technical Requirements for Inland Navigation Vessels (later: ES-TRIN[10]) were developed with a new edition entering into force on January 2022 (Pater – de Groot, 2021).

In accordance with the scoping exercise of the IMO, the MSC has approved interim guidelines[11] for MASS trials in June 2019. The guidelines dictate that the trials should be conducted in a manner that guarantees the same safety, security, and protection of the environment conditions as conventional vessels. Risks should be assessed prior testing and appropriate measures should be taken. The guidelines also set standards for the training, qualification and experience of personnel conducting MASS trials. Lastly, it is stated that measures should be put in place to ensure sufficient cyber security risk management of systems and infrastructure when testing autonomous vessels (IMO, 2021). Even though the IMO focusses on sea-going vessels, these guidelines and scoping exercise can be of importance to the autonomous inland navigation as well.

3.2. Belgium

Due to the complex structure of the Belgian state the Belgian waterways are subject to a number of different rules and regulations. This section will discuss federal law and the regulations applicable on the regions of Flanders and Wallonia.

The Royal Decree of October 25th 1935[12] is still in use today and determines the regulations regarding the conditions ships need to meet to use the shipping routes in Belgian territory. The Royal Decree of September 24th 2006[13] establishes the general police regulation concerning inland shipping in Belgium. The Royal Decree of March 9th 2007[14] contains regulations regarding crew. The new Belgian shipping code[15] (BSC) was ratified in 2019 replacing the old Maritime Code of 1879 (Van Hooydonk, n.d.), and regulates among other subjects, the inland

[9] Convention on the Limitation of Liability in Inland Navigation, Strasbourg, 27th September 2012
[10] European Standards laying down Technical Requirements for Inland Navigation Vessels, 13th October 2020
[11] Interim Guidelines for MASS Trials, June 14th 2019
[12] Koninklijk Besluit van 25 oktober 1935 houdende het algemeen regelement der scheepvaartwegen van het koninkrijk
[13] Koninklijk Besluit van 24 september 2006 houdende vastelling van het algemeen politiereglement voor de scheepvaart op de binnenwateren van het Koninkrijk
[14] Koninklijk Besluit van 9 maart 2007 houdende de bemanningsvoorschriften op de scheepvaartwegen van het koninkijk
[15] Wet van 8 mei 2019 tot invoering van het Belgisch Scheepvaartwetboek

shipping in Belgium, keeping in mind the sixth state reform where the powers regarding inland shipping were transferred to the regions.

3.2.1. Flanders

The Royal Decree of September 23rd 1992[16] contains the shipping code on the canal Ghent-Terneuzen. The region called 'Beneden Zeeschelde' is regulated by the Royal Decrees of September 23rd 1992[17,18]. Ships on the common river Meuse need to follow the law of March 15th 2002[19]. Further regulations regarding the transportation of dangerous goods regulated by the Decree of July 6th 2012[20] and the Decision of the Flemish Government of May 21 2021[21].

When it comes to autonomous shipping Flanders has taken a leading role as it is the first region to create a legal framework allowing autonomous and unmanned ships to be tested in the Flemish waterways (Ann-Sofie Pauwelyn[22], pers. com., 2022, March 2). The first activities were made possible by the Decree of April 26 2019[23] followed by the Collective Decree[24] where the provisions of the previous decree were copied.

3.2.1.1. Testing procedure

If a company or organization wants to test autonomous vessels on the waterways of the Flemish Waterway nv they must complete a testing procedure (see Annex 10.1). First, the Single Point of Contact (SPOC) of the Agency for Maritime and Coastal services, specifically the Flemish Vessel Traffic Services (VTS) – Scheldt area, must be contacted. The SPOC will then send an

[16] Koninklijk Besluit van 23 september 1992 houdende scheepvaartreglement voor het Kanaal van Gent naar Terneuzen
[17] Koninklijk Besluit van 23 september 1992 houdende scheepvaartreglement voor de Beneden-Zeeschelde
[18] Koninlijk Besluit van 23 september 1992 houdende politiereglement van de Beneden-Zeeschelde
[19] Wet van 15 maart 2002 houdende instemming met de Overeenkomst tussen het Koninkrijk België en het Koninkrijk der Nederlanden tot regeling van het scheepvaartverkeer en van de recreatie op de gemeenschappelijke Maas
[20] Decreet van 6 juli 2012 betreffende het vervoer van gevaarlijke goederen over de binnenwateren
[21] Besluit van de Vlaamse regering van 21 mei 2021 tot wijziging van het besluit van de Vlaamse Regering 25 mei 2018 tot aanpassing van de regelgeving betreffende het vervoer van gevaarlijke goederen over de binnenwatern aan de wetenschappelijke en technische vooruitgang wat betreft de voorwaarden waaronder het vervoer van gevaarlijke goederen over de binnenwateren is toegestaan
[22] *Ann-Sofie Pauwelyn* is Smart Shipping Project Leader in the Flemish Inland Waterway Authority (De Vlaamse Waterweg nv), department Automation and Traffic Management. She is the expert when it comes to autonomous shipping inside the Flemish Government.
[23] Decreet van 26 april 2019 betreffende diverse bepalingen over het mobiliteitsbeleid, de openbare werken en het vervoer, het verkeersveiligheidsbeleid en VVM - De Lijn, *BS* 24 juni 2019
[24] Ontwerp van decreet van 19 januari 2021 betreffende het scheepvaartdecreet, Parl.st. Vl. Parl 2021-2022, nr. 1007/6

application form consisting of three forms: a concept of operations, a gap analysis of the police regulations and a risk analysis.

The Evaluation Committee of the Flemish Waterway nv will assess this application withing six weeks. After approval the company or organization will be invited for an interview regarding the practical matters. This approval essentially means an exemption on certain rules and regulations. This exemption has a validity period of one year and can be extended to five years. The tests can then be performed, always following the code of conduct (See Annex 10.2) and the agreement (Vlaamse Waterweg, 2018). The code of conduct is based on the code of conduct for testing autonomous vehicles in Belgium and contains the scope of application, definitions of autonomous shipping, general requirements, requirements for testers, test operators and test assistants and the vessel requirements (Vlaamse Waterweg, 2018).

During testing the organization or company will report in their results. The report will consist of a description of the testing activities, including the date, position, and time. It will also include a description of the issues encountered while testing and how they were resolved. The report must be sent to the SPOC within two weeks after the tests have ended (Vlaamse Waterweg, n.d.).

3.2.2. Wallonia

In Wallonia they are also planning on adapting regulations in order to permit testing of autonomous ships or ships with a limited crew on board, but they haven't progressed nearly as far as their Flemish colleagues. For now, authorities are yet to establish a procedure for applicants to introduce a request to carry out tests on Walloon Inland Waterways. There have not been any tests on the waterways yet even though a Flemish test procedure is already being used (C. Dumoulin[25], pers. com., 2022, March 7).

[25] *Chloé Dumoulin* is a legal counselor with the Public Service of Wallonia and is in charge of the scoping exercise regarding legislation and test procedures for autonomous shipping.

4. Legal challenges

This section will review the different legal challenges that autonomous shipping is facing today. First there will be an overview of the major concerns formulated by scholars. Then the outcome of the regulatory scoping exercise by the IMO will be discussed, followed by a gap analysis of current national and international legislation.

4.1. Scholars

Since autonomous shipping is becoming a valid alternative for conventional shipping, but currently has no legal framework, scholars have researched the legal challenges and issues regarding autonomous shipping. The most important issue is the absence of humans on board in regard to insurance and liability, a few major concerns were formulated, and solutions were proposed.

4.1.1. Liability

As previously discussed, human errors are the main cause of accidents in the maritime sector. The introduction of autonomous ships will reduce the number of accidents caused by humans but will introduce a new issue: who will be held liable for faults if they are not directly generated by human interference? Sensor fault and software bugs are inherent risks and already exist in automated ships that are used today (Westgård, 2021). Algorithms may make mistakes due to a lack of training of the programme but may also be caused by a mistake of the programmer. Who will be held liable for a programme that wasn't trained properly and who will take responsibility for the mistakes of the programmer? The answers to the questions will probably be answered by future case law.

4.1.2. Master's role

The second concern is the role of the captain on board the ship. The master has the sole command of the ship and is in charge of maintaining the ship's health, safety, security and environmental compliance (Li & Fung, 2019). The captain is responsible for maintaining the seaworthiness of the ship, he has multiple public authorities and represents the shipowner on board. These duties and responsibilities are described in international treaties and domestic legislation and have not changed significantly over the past hundred years (Li & Fung, 2019; Vojković & Milenković, 2020). Another role of the master is the navigation. The captain must be physically on board as it is stated that in case of absence of the master, the chief officer should replace him. The question remains what will happen to the different duties and responsibilities of the captain in the various stages of autonomy (Delgado, 2018; Vojković & Milenković, 2020)?

In case of AAB, the bridge is still manned which will not go against current rules and regulations. There will be no need for any special regulatory measures although performance standards for newly introduced bridge functions would be recommended. This same logic applies to ships sailing with a PUB, the crew is still on board in case the system detects a problem. The PUS and CUS are the autonomy levels causing issues with the current regulatory framework (Rødseth & Nordahl, 2017).

4.1.3. On Board crew

Safe manning levels are required by different national and international legislation not only for safety but also to determine if the vessel is allowed to sail. In most cases concerning seagoing ships the absence of crew causes issues with the seaworthiness of the vessel and the application of the Hague-Visby Rules regarding cargo claims (Carey, 2017). As the Hague-Visby Rules are not applicable to inland vessels, this falls outside the scope of this paper. Domestic (Belgian) legislation, however, also has requirements regarding crew size. These issues will be discussed in section 4. The legal issues regarding crew size could be resolved by sailing with a full crew (see Seafar abroad), slow steaming will still be possible but then costs related to the crew (accommodation, safety measures, food etc.) would remain, making autonomous shipping less interesting.

The absence of security officers and personnel on board an autonomous vessel presents a serious security gap. This gap needs to be remediated by the appropriate risk mitigation systems or the obligations regarding security need to be altered. This can be done by checking the safety and security of each vessel before it leaves to another port and would result in extra costs related to the maintenance of the ship (Komianos, 2018).

4.1.4. Response to emergencies

Even though emergencies in inland waterways can be remediated rather quickly by other emergency vessels, ships still have the obligation to offer assistance in distress situations. The rendering of assistance must normally be decided by the captain on board. Will this duty be transferred to the master onshore? (Komianos, 2018). What happens in case of an emergency with a passenger vessel when there is no captain on board? What happens when a passenger needs to be restrained or a crew member has committed a violation? (Vojković & Milenković, 2020).

4.1.5. Insurance

The introduction of autonomous ships and the new type of accidents related to that has created a new branch within the maritime insurance sector. The phenomenon is so new that current insurance measures aren't equipped to deal with the risks of the autonomous transport mode. In certain cases of autonomous navigation there is no captain on board and the vessel is steered by a computer system. When an incident occurs in this situation it is not clear who will be responsible and held liable. Currently Proteus Risk Solutions and Vanbreda Risk & Benefits have developed a policy in cooperation with the insurer MS Amlin for their Mahi One project (Note & Olyslagers, 2019). The policy was developed in cooperation between insurers and customers keeping in mind the safety, navigational system and technology, controls, and worst-case scenarios. The traditional policy was examined and gaps were identified (K. Olyslager[26], pers. com., 2022, April 5).

4.1.6. Traffic regulations inland waterways

The last concern is about the traffic regulations in inland waterways. They are regulated by international and domestic instruments. It is expected that the general traffic regulations and the General Police Regulation for inland waterway vessels contain rules from which cannot be deviated and need to be addressed and adapted before the implementation of autonomous vessels (Pauwelyn & Liégois, 2019).

Most scholars research the impact of autonomous sea-going vessels on international instruments and although the same logic can be followed in autonomous inland vessels, only certain international legislation is applicable to inland ships in certain situations. Therefor it is important to look at the different kinds of conventions, directives, decrees and laws and asses them against the concept of autonomous inland navigation (see 4.3. and 4.4.).

[26] *Kristof Olyslager* is a marine insurance broker at Vanbreda Marine and helped develop the policy for the Mahi One Project.

4.2. IMO – scoping exercise

The IMO tries to integrate new and revolutionary shipping technology in regulatory frameworks taking into account safety and security concerns, environmental impact, potential costs to the industry and the impact on personnel on board and on shore. The IMO has recently completed their regulatory scoping exercise[27] on MASS in accordance with their strategic plan (2018-2023), and by doing so assessed the existing instruments to see how they could be used on vessels with different degrees of autonomy. The report highlights a number of issues that need to be addressed at a policy level (IMO, 2021).

The report states that an internationally agreed terminology and definition of MASS needs to be established. Adding to that the terms of 'master', 'crew' and 'responsible person' need to be adjusted to fit the unmanned autonomous vessels. Also, specific legal concepts like 'fault', 'negligence' and 'intention' need to be addressed. Furthermore, the functional and operational requirements of the SCCs and remote operator need to be drafted and gaps between different treaties need to be identified (IMO, 2021).

For each instrument related to safety, security, liability, and compensation during the maritime adventure, provisions were identified according to the degree of autonomy. Some provisions applied to MASS and prevented the operations, others didn't, some needed to be amended or clarified and others had no application to MASS operations. The IMO used the degrees of autonomy previously mentioned in section 1.1.1.

Table 1. List of common potential gaps and/or themes (IMO, 2021)

	Common potential gaps and/or themes	**Instruments**
1	Meaning of the terms master, crew, responsible person	SOLAS chapters II-2, III, V, VI, VII IX and XI-1, COLREG, TONNAGE 1969, 1966 LL Convention and 1988 Protocol, Intact Stability Code, III Code, STCW Convention and Code
2	Remote Control Station/Centre	SOLAS chapters II-1, II-2, III, IV, V IX and XI-1, STCW Convention and Code, FSS, ISM, 1966 LL Convention and 1988 Protocol, Casualty Investigation Code
3	Remote Operator as a seafarer	STCW, STCW-F, SOLAS chapter IX, ISM
4	Provisions containing manual operations, alarms to the bridge	SOLAS chapters II-1, II-2, VI and IX, 1966 LL Convention and 1988 Protocol, Intact Stability Code, III Code

[27] Outcome of the regulatory scoping exercise for the use of Maritime Autonomous Surface Ships (MASS), London, 3 June 2021

5	Provisions requiring actions by personnel (Fire, Spillage, Cargo Management, onboard management, maintenance etc.)	SOLAS chapters II-2, VI, VII, IX and XII
6	Certificates and manuals on board	SOLAS chapters III, XI-1, XI-2 and XIV
7	Connectivity, cybersecurity	SOLAS chapters IV, V and IX
8	Watchkeeping	SOLAS chapters IV and V, COLREG
9	Implications of MASS and SAR	SOLAS chapters III, IV and V, SAR
10	Information to be available on board and required for safe operation	SOLAS chapters II-1and II-2
11	Terminology	SOLAS chapters II-1, IV and V, COLREG, FSS, IBC, IGC, Grain, INF, 1966 LL Convention and 1988 Protocol, Intact Stability Code, SAR, TONNAGE, CSS, Casualty Investigation Code

The outcome of the regulatory scoping exercise was approved by the MSC at its 103rd session from 5 to 14th May 2021. The IMO focused on sea-going autonomous ships and the corresponding international rules and regulations, but the issues that were summed up in the report reflect the issues of autonomous inland navigation as some international conventions also apply to inland waterways.

4.3. International legislation

In order to formulate the present legal challenges regarding the implementation of autonomous shipping we must first perform a gap analysis on the current legal framework. This to identify the sections of international legislation that need to be adapted in order to allow autonomous ships to perform according to the law.

4.3.1. The 1910 Collision Convention

Table 2. 1910 Collision Convention – Scope and problematic articles

Art. 1	Where a collision occurs between sea-going vessels or between sea-going vessels and vessels of inland navigation, the compensation due for damage caused to the vessel, or to any things or persons on board, therefore, shall be settled in accordance with the following provisions, in whatever waters the collision takes place.
Art. 2	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.
Art. 5	The liability imposed by preceding articles attaches in cases where the collision is caused by the fault of a pilot even when the pilot is carried by compulsion of the law.
Art. 8	After a collision, the master of each of the vessels in collision is bound, so far as he can do so without serious danger to his vessel, her crew and her passengers, to render assistance to the other vessel, her crew and her passengers. He is likewise bound so far as possible to make known to the other vessel the name of his vessel and the port to which she belongs, and also the names of the ports from which she comes and to which she is bound. A breach of the above provisions does not of itself impose any liability on the owner of a vessel.

According to **article 1** of the 1910 Collision Convention, the convention is applicable to inland vessels colliding with sea-going vessels in whatever waters and could therefore be applicable to autonomous inland vessels, for example when a collision was to happen in a port area.

Article 2 mentions force majeure, but what could be considered as force majeure in autonomous vessels? Force majeure is usually defined as "an excuse used in any circumstance which has prevented the performance of any contractual obligation, wherein such event was not foreseeable at the time of signing the contract" (Elhais, 2021). One could argue that a malfunction of the navigational system or the loss of satellite connection falls under force majeure causing the damage to be borne by both suffering parties. One could also argue that a malfunction was caused by mal programming of the system or negligence, in that case the accident would fall under art. 5.160 of the Civil Code and the owner of the vessel would be responsible. A detailed definition of force majeure would therefore be favorable.

Article 5 indicates the use of pilots, but how relevant will pilots be in the context of autonomous vessels? If vessels are built without a navigation bridge pilots may not be able to board and steer a vessel in a port. It could be a possibility that pilots are located in a SCC and take over control of the vessel when needed, in which case the convention should stipulate that the pilot doesn't have to be on board for the convention to be applicable (Pribyl & Weigel, 2018).

Article 8 states that the master is bound to render assistance in case of a collision, but how will the master do this when he/she is not physically on board? Or even when the vessel is navigating on its own and there is no master, can the legal duty to render assistance continue to exist? (Coito, 2021). The interpretation of this article thus largely depends on the degree of autonomy of the vessel. The first two degrees of automation pose no difficulties as there are still seafarers on board, the third and fourth degree of autonomy require an adjustment or specification of the convention (Rødseth & Nordahl, 2017).

4.3.2. 1952 Brussels Civil Jurisdiction Convention

Table 3. 1952 Brussels Civil Jurisdiction Convention – Scope and problematic articles

Art. 1	An action for collision occurring between seagoing vessels, or between seagoing vessels and inland navigation craft […] […] or before the Court of the place of collision when the collision has occurred within the limits of a port or in inland waters.

According to **article 1** of the 1952 Brussels Civil Jurisdiction Convention, the convention is applicable to inland navigation craft colliding with sea-going vessels in inland waters. Inland navigation craft is not further specified in the convention; therefore, the text could be applicable to autonomous vessels as well without adjustments.

4.3.3. COLREGS

Table 4. COLREGS – Scope and problematic articles

Rule 1	(a) These Rules shall apply to all vessels upon the high seas and in all water connected therewith navigable by seagoing vessels. (b) Nothing in these Rules shall interfere with the operation of special rules made by an appropriate authority for roadsteads, harbor, rivers, lakes or inland waterways connected with the high seas and navigable by seagoing vessels. Such special rules shall conform as closely as possible to these Rules.
Rule 2	(a) Nothing in these Rules shall exonerate any vessel, or the owner, master or crew thereof, form the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or by the special circumstances of the case.
Rule 3	(a) The word 'vessel' includes every description of water craft, including non-displacement craft, WIG craft and seaplanes, used or capable of being used as a means of transport on water.
Rule 5	Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.
Rule 8	Any action to avoid collision shall be taken in accordance with the Rules of this Part and shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship.

The COLREGS contain rules on preventing collisions at sea. **Rules 1 (a)** and **(b)** and **3 (a)** contain the scope of application of the COLREG. It is mentioned that the convention applies to all vessels and on all waterways that can be navigated by seagoing vessels, this includes inland waterways as some sea-going vessels can sail here as well. Whether or not the COLREG applies to inland vessels is a point of discussion, but if we follow the letter of the law, we could assume as much.

Rule 2 (a) and **8** imposes good seamanship and places this responsibility with the vessel, owner, master, or the crew of the ship. As the ship itself is also mentioned, this could mean that the responsibility could lie solely with the vessel and consequently would not pose any problems towards autonomous vessels. However, the COLREGs were drafted assuming there would always be humans on board to steer the vessel and eventually take responsibility, which is not the case in autonomous ships (Carey, 2017).

Rule 5 demands a proper look-out by sight and hearing at all times. The way this sentence was formulated suggests that a human needs to be present as they have the ability to see and hear. A ship can only detect and react according to the information she received, she can't hear or see in the human meaning of the words. COLREGs then adds "as well as all available means […]", which means the ship can also use audio-visual methods such as radar. Autonomous ships will be equipped with the newest technology resulting in an accurate image regarding the surroundings. The "all available means" will also be far more advanced than the ones used by conventional ships. Nonetheless, COLREGs makes it clear that these means can be used "as well as" look-out by sight and hearing. As there will be no physical human presence on board of an autonomous vessel with an autonomy degree of three or four, compliance with this article is not possible for these kinds of vessels.

The COLREGs need to be adjusted to fit vessels without a human presence on board (autonomy degree three and four). This can be done by changing the formulation of the term 'seamanship' and "look-out by sight and hearing".

4.3.4. CEVNI

Table 5. CEVNI – Scope and problematic articles

Art. 1.01	1.	The term "vessel" means any inland waterway craft including small craft and ferry-boats, as well as floating equipment and seagoing vessels.
	12.	The term "waterway" means any inland water open to navigation
Art. 1.02	1.	Every vessel or assembly of floating material, except vessels in a pushed convoy other than the pusher, shall be placed under the authority of a person having the necessary qualifications. This person is hereinafter referred to as the boatmaster. Boatmasters are considered to possess the necessary qualifications if they hold a valid boatmaster's certificate.
	3.	when a vessel is under way the boatmaster shall be on board; in addition, the boatmaster of floating equipment shall always be on board when the equipment is in operation
	5.	Every floating establishment shall be placed under the authority of a person. This person shall be responsible of the observation of these regulations on the floating establishment.
	7.	In the case of a moored vessel or assembly of floating material having no boatmaster, the person responsible for ensuring compliance with the provisions of these regulations shall be: (a) The person responsible for keeping watch and surveillance under article 7.08 (b) The operator and owner of such vessel or assembly if the person referred to in letter (a) is absent.
Art. 1.03 & 1.04		Duties of crew and other persons on board
Art. 1.09	1.	When under way, a vessel shall be steered by at least one qualified person of not less than 16 years.
	3.	In order to ensure proper control of the vessel, the helmsman shall be able to receive and give all information and all orders reaching or proceeding from the wheelhouse. In particular, he shall be able to hear sound signals and have a sufficiently clear view in all directions.

	4.	When particular circumstances so require, a look-out or listening-post shall be set up to keep the helmsman informed.
	5.	When under way, all high-speed vessels shall be steered by a person not younger than 21 years of age who has the necessary qualifications referred to in article 1.02, paragraph 1 and the certificate referred to in article 4.06, paragraph 1 (b). A second person who also holds these documents shall be in the wheelhouse except during berthing and casting off and in locks and their forebays.
Art. 1.10	1.	The following documents shall be available on board: […]
Art. 1.16	1.	In the event of an accident endangering persons on board, the boatmaster shall use every means at his disposal to save them.
	2.	Every boatmaster who is close to a vessel or assembly of floating material which has suffered an accident endangering persons or threatening to obstruct the fairway is required to give immediate assistance insofar as is consistent with the safety of his own vessel.
Art. 1.17	1.	[…] In the case of a grounded or sunken vessel, the boatmaster or a member of the crew shall remain on board or near the site of the accident until the competent authority has authorized them to leave.

The CEVNI regulates the traffic for inland waterways in the UNECE region regarding the draught of the vessels, visual signals, prevention of pollution etc. Any article that mentions the boatmaster, poses a problem for autonomous vessels with an autonomy degree of four; when the crew is involved, a third-degree vessel does not comply either. The CEVNI is very focused on boatmasters and crew being on board as seen in table 5. When the duties and responsibilities are directly transferred from the boatmaster to the captain in the SCC, most issues for autonomous vessels until the third degree would be solved. Fourth degree autonomous vessels remain incompliant with the current code unless a few adjustments are made to chapter 1 General Provisions.

According to **article 1.01** this code is only applicable to inland vessels navigating in inland waterways. **Article 1.02** contains the general provisions regarding the boatmaster. (1&5) The vessel must be placed under authority of a person with the right qualifications. Even though "under authority" can be open to interpretation, when looking at (3), the boatmaster must be on board at all times when the vessel is under way. This is an issue for vessels with an autonomy degree of two or higher, the boatmaster or captain then controls the vessel from a SCC or the vessels sails fully autonomous.

Article 1.09 dictates that the vessel must be steered by at least one qualified person, aided by a helmsman who receives his order from the wheelhouse. It is again made clear that the one steering the vessel and the crew must be on board. **Article 1.10** indicates which documents must be on board of the vessel, including the boatmaster's certificate. When dealing with autonomous vessels the focus should be on online documents. If officials require the documents, they could contact the SCC and verify the papers digitally.

Articles 1.16 and **1.17** describe the procedure in case of an accident. The boatmaster must remain on board and do everything to save the persons endangered and give them assistance. In case of autonomous vessels (degree two and up) there is no boatmaster on board to fulfill this duty.

4.3.5. Salvage Convention

Table 6. Salvage Convention – Scope and problematic articles

Art. 1	(a) Salvage operation means any act or activity undertaken to assist a vessel or any other property in danger in navigable waters or in any other waters whatsoever. (b) Vessel means any ship or craft, or any structure capable of navigation
Art. 10	1. Every master is bound, so far as he can do so without serious danger to his vessel and persons thereon, to render assistance to any person in danger of being lost at sea.
Art. 30	Any states may, at the time of signature, ratification, acceptance, approval, or accession, reserve the right not to apply the provisions of this Convention: (a) When the salvage operation takes place in inland waters and all vessels involved are of inland navigation (b) When the salvage operations take place in inland waters and no vessel is involved.

The Salvage convention governs (marine) salvage in case of collisions or accidents. **Article 1** states the Convention is applicable in all navigable waters or in any waters whatsoever. **Article 30** on the other hand provides the possibility for countries to make reservations when the salvage operation takes place in inland waters. According to the 1989 Salvage Convention Questionnaire Belgium and its different regions have ratified and incorporated the Convention in its national law without any reservations or restrictions. The provision regarding salvage can be found in article 2.7.5.1 BSC, this will also be discussed in section 4.4.1.4

Article 10 states that every master is bound to render assistance to any person in danger of being lost at sea (or any other waters whatsoever). This action is only required when the master can assist without endangering his own ship, the crew, and the passengers. This places a personal obligation on the master and causes a major issue for autonomous ships of the third and fourth degree of autonomy. A ship without a captain but with a crew on board (degree two) can still render assistance to a vessel in need, a ship without captain nor crew cannot. The captain (degree three) or the ship (degree four) can then only alert other ships or authorities (Carey, 2017)

4.3.6. CMNI

Table 7. CMNI – Scope and problematic articles

Art. 2	2.	This Convention is applicable if the purpose of the contract of carriage is the carriage of goods, without transshipment, both on inland waterways and the waters to which maritime regulations apply, under the conditions set out in paragraph 1, unless: […]
Art. 3	3.	The carrier shall decide which vessel is to be used. He shall be bound, before and at the beginning of the voyage, to exercise due diligence to ensure that, taking into account the goods to be carried, the vessel is in a state to receive the cargo, is seaworthy and is manned and equipped as prescribed by the regulations in force and is furnished with the necessary national and international authorizations for the carriage of the goods in question
Art. 16	1.	The carrier shall be liable for loss resulting from […], unless he can show that the loss was due to circumstances which a diligent carrier could have prevented and the consequences of which he could not have averted.

The Budapest Convention regulates the contract for the carriage of goods by inland waterways. **Article 2.2** states the CMNI is applicable to inland waterways and the waters to which maritime regulations apply. Furthermore, the General Provisions of the Budapest Convention do not define the term ‘vessel’, so in this respect the Convention does not pose any problems regarding the application to autonomous vessels in inland waters.

Article 3.3 describes the rights and obligations of the carrier. It is said that the carrier must make sure that the vessel is seaworthy, but what makes a vessel seaworthy? The seaworthiness of a vessel is not just the state of the ship and its equipment but also the crew and cargo worthiness, this requires a minimum of crew members and a captain to be on board. However, seaworthiness has been defined in many different ways throughout case law and is therefore open to interpretation (Kirchner, 2019). The article continues by stating that the vessel should be manned and equipped as prescribed by the regulations in force. The conditions of seaworthiness and especially manning levels of the vessel will be problematic when introducing autonomous vessels, especially of the third and fourth degree.

Article 16 determines the liability of the carrier, but also describes an exoneration comparable to *force majeure*. Whether or not the introduction of autonomous vessels will add a new meaning to force majeure is yet to be seen. A short reasoning was already discussed in section 4.1.1 and 4.3.1.

4.3.7. ADN

Table 8. ADN (and annexes) – Scope and problematic articles

Art. 1	1.	This Agreement shall apply to the international carriage of dangerous goods by vessels on inland waterways.
Art.3	(a)	"vessel" means an inland waterway or seagoing vessel
Section 1.10.1.4		For each crew member of a vessel carrying dangerous goods, means of identification, which includes a photograph, shall be on board during carriage.
Section 8.1.2		Documents […] the following documents shall be kept on board […]

This European Agreement contains standards and good practices for the carriage of dangerous goods. It aims at ensuring a high level of safety of international carriage of dangerous goods and therefore contributes to the effective protection of the environment by preventing pollution. **Article 1** and **3** suggests that the use of autonomous vessels would be a possibility, but due to the precarious nature of the goods it would not be recommended.

Section 1.10.1.4 and **8.1.2** contain provisions regarding the required documents on board. A suggestion would be to digitalize these documents if autonomous vessels would appear to be an option in the carriage of dangerous goods in inland waters. This suggestion is only relevant for autonomous vessels of the third and fourth degree.

4.3.8. CLNI

Table 9. CLNI – Scope and problematic articles

Art. 1	(b)	"vessel" shall mean an inland navigation vessel used for commercial navigational purposes and shall also include hydrofoils, ferries and small craft used for commercial navigational purposes but not air-cushion vehicles. Dredgers, floating cranes, elevators and all other floating and mobile appliances or plant of a similar nature shall also be considered vessels
	(e)	"waterway" shall mean any inland waterway, including any lake

This convention contains provisions that limit the liability in inland navigation and is based on the Convention of Limitation of Liability for Maritime Claims (LLMC). **Article 1** (a) and (e) clarify the terminology used in the convention. The definition of 'vessel' is quite broad, and we therefore predict no issues regarding the introduction of autonomous vessels of any degree used for inland navigation. The term 'waterways' is used for inland waterways which fits into the scope of this thesis. There are no other articles in this convention that would be problematic for the implementation of autonomous vessels.

4.3.9. ES-TRIN

Table 10. ES-TRIN – Scope and problematic articles

Art. 1.01	1.2	‘Vessel’: an inland waterway vessel or sea-going ship
	1.3	‘Inland waterway vessel’: a vessel intended solely or mainly for navigation on inland waterways.
Chapter 7	Wheelhouse	
	1.	Wheelhouses shall be arranged in such a way that the helmsman may at all times perform his task while the vessel is under way
Article 10.01	2.	For unmanned craft, these documents shall not be required to be on board but shall at all times be available with the owner.
Chapter 15	Accommodation	
	1.	Vessels shall have accommodation for the persons lodging habitually on board, and at least for the minimum crew
Chapter 16	Fuel-fired, cooking and refrigerating equipment	
Chapter 17	Liquified gas installations for domestic purposes	
Chapter 18	On-board sewage treatment plants	
	1.	‘On-board sewage treatment plant’: a sewage treatment plant of compact design for treating the quantities of domestic wastewater accruing on board

This document lays down the European standards for the technical requirements for inland navigation vessel. According to **article 1.01** (**1.2**) and (**1.3**) the standards fit into the scope of this paper.

Chapter 15, 16, 17 and **18** lay down the standards for the accommodation, equipment, installations, and sewage plants. However, autonomous vessels of the third and fourth degree won’t require any of this as there will be no crew on board and removing these components is part of saving building and fuel cost (see section 2.3.4). **Chapter 7,** on the other hand, could be open to interpretation. The wheelhouse is defined as “the area which houses all the control and monitoring instruments necessary for maneuvering the vessel” (art. 1.01, 3.6). According to this definition the SCC could technically be seen as a wheelhouse away from the ship, located on shore. Apart from the technical requirements needed to build a functioning vessel and the article open to interpretation, an autonomous vessel will never be able to comply with the standards imposed by this document.

ES-TRIN is a fairly recent document (2012, with the latest edition being ed. 2022) and thus takes into account the possibility of unmanned vessels. **Article 10.01** briefly mentions it when summing up the documents that are required to be on board. Even though unmanned and autonomous vessels are not the same, it is a step in the right direction of incorporating autonomous ships in rules and regulations.

4.4. National legislation

This section contains the gap analysis of the current Belgian legal framework regarding shipping in inland waterways. As a result of the sixth sate reform the northern inland waterways are governed by the Flemish region, the southern waterways by the Walloon region and the 14km inland waterways in the center of the country are governed by the Brussels-Capital region (FOMV, 2014). The gap analysis will be performed on federal and Flemish legislation.

4.4.1. Federal

4.4.1.1. Royal Decree October 25th, 1935

Table 11. Royal Decree October 25th, 1935 – Scope and problematic articles

Art. 6	Elk schipper of elk voor de binnenvaart te werken gesteld persoon die door nalatigheid,onbekwaamheid, dronkenschap of vrijwillige slechte wending, stoornis veroorzaakt, de vaart der vaartuigen, vlottreinen of vlotten hindert of vertraagt, wordt gestraft volgens artikel 100 van dit reglement. Op de eerste vordering moet de kapitein of schipper den overtreder onmiddellijk vervangen.
Art. 7	Elk vaartuig, […] waarbij de eerste medische hulpmiddelen in nijverheids- en handelsondernemingen worden voorgeschreven, is bepaald dat : "Op de treinen, trams, trekmachines, sleepbooten, lichters, baggerschuiten en, over 't algemeen, op de door een krachtwerktuig voorgetrokken voer- en vaartuigen, waarvan het in werking brengen vereischt : a) één tot vijf personen : een verbandtrommel nr 1; b) meer dan vijf personen : een verbandtrommel nr 2", verplicht is.
Art. 8	Elke schipper moet in het bezit zijn: […]De schipper moet genoemde stukken vertonen op elke vordering vanwege de agenten van de waterweg en van de ambtenaren belast met het innen van en het toezicht op de scheepvaartrechten. Desnoods dient hij zich daartoe aan wal te begeven. Aan boord moet hij de naamlijst vertonen samen met de officiële identiteitsbewijzen van de aanwezige manschappen.
Art. 47bis	Bij vriesweer zijn de eigenaars of schippers van vaartuigen verplicht het ijs, dat zich rondom hun schepen mocht vormen, te breken en gebroken te houden.
Art. 107	1. De naam "vaartuig": elk schip, elke schuit, boot, die op zee, op de rivieren of kanalen gebruikt worden; 2. De naam "schipper": ieder gezagvoerder, kapitein, schipper en, in het algemeen, elk persoon die aan boord het gezag voert of met de leiding van het vaartuig belast is;

The Royal Decree of October 25th, 1935 contains the general rules regarding shipping in inland waterways in Belgium. The document was altered by the Royal Decree of January 21st, 1998 due to it being outdated after 60 years, most changes were made regarding the tonnage certificate.

Article 107.1 gives the definition of a vessel, as it is a rather broad definition, it could also be used for autonomous ships in inland waterways. **Article 107.2** defines the ‘shipper’ or the ‘captain’ of the ship and dictates that this person is on board and in charge of the vessel. Vessels with an autonomy degree of two or higher won’t comply with this article.

Article 6 dictates that the person who hinders the inland journey will be punished according to art. 100 of the decree and will be replaced immediately. According to **article 107**, they assume the shipper is on board, this article can be applied to people steering the vessel from the SCC. The interpretation of the article will be a matter of case law.

Article 7 contains regulations regarding certain supplies that must be on board to guarantee a swift and timely transport. One could argue that this article is already adapted to the use of autonomous ships as there only have to be medical supplies on board when there is at least a crew of one. **Article 8** sums up the documents that must be on board and should be able to be presented at all times if asked by the waterway police. When a vessel is sailing autonomously, chances are these documents will not be on board and no crew will be present to show them. This results in another question: how will police officers check autonomous vessels sailing in inland waterways?

Article 47bis contains a provision regarding what to do in case of icy weather. The shippers must then break the ice and keep it broken; how will an autonomous vessel ensure this?

The mentioned articles have a rather small influence on the legality of the use of autonomous vessels in inland waterways as it is an older document that has been amended by more recent decrees, but they need to be mentioned none the less. Another remark is that a lot of articles from this decree were lifted for the Flemish Region, except for the canal between Brussels and Charleroi.

4.4.1.2. Royal Decree September 24th, 2006

Table 12. Royal Decree September 24th, 2006 – Scope and problematic articles

Art. 1.01	a)	Schip of boot: elk vaartuig met inbegrip van een voorwerp zonder waterverplaatsing en een watervliegtuig, gebruikt of geschikt om gebruikt te worden als een middel van vervoer te water.
		Bijzondere types van schepen
Art. 1.02	1.	Ieder schip […] dient te worden geplaatst onder het gezag van een persoon die de geschikte kwalificaties bezit.

	3.	Bij het varen dient de schipper aan boord te zijn, […]
Art. 1.04	2.	De schipper moet, ook bij ontbreken van uitdrukkelijke voorschriften in dit reglement, alle voorzorgsmaatregelen nemen die door de algemene plicht van waakzaamheid volgens de omstandigheden waarin het schip zich bevindt, of volgens het goede zeemanschap geboden zijn, teneinde meer bepaald te vermijden
Art. 1.08	2.	Alle schepen en drijvende voorwerpen, […], moeten een bemanning hebben die voldoende in aantal is en gekwalificeerds ten einde de veiligheid te verzekeren van de personen aan boord en van de scheepvaart. […]
Art. 1.09		Sturen van een schip
Art. 1.10		Boorddocumenten
Art. 1.16		Redding en bijstand.
Art.4.06 **Art. 6.32**	1	Een schip mag slechts gebruik maken van een radar en een Inland ECDIS apparaat […] voor zover: b) Zich aan boord aan persoon bevindt die houder is van een diploma dat overeenkomstig de daaromtrent vastgestelde regelen is afgegeven

This royal decree contains all general police regulations for shipping on inland waterways. **Article 1.01. a.** describes the definition of a ship. This is again a very broad definition, including crafts normally not defined as ships, so there shouldn't be any problems regarding autonomous ships. **Article 1.01** also mentions special types of ships, it could be an idea to define autonomous ships in this section.

Article 1.02. **1.** dictates that the ship should always be placed under the authority of a person with the right qualifications. Autonomous vessels with an autonomy degree of two or three still comply with this article as there is a captain steering the vessel in a SCC. Autonomous vessels of the fourth degree are fully autonomous and don't have a person of authority with the right qualifications. **Article 1.01. 3.** Also mentions that the shipper has to be on board during navigation, autonomous vessels (second degree and higher), cannot comply with this article.

Article 1.04 discusses the duty of vigilance and 'good seamanship' of the captain. One could argue that a captain can still be vigilant to the circumstances when operating from an SCC. This would solve non-compliance for vessels of the second and third degree of autonomy. The considerations regarding 'good seamanship' were already mentioned above.

Article 1.08 imposes a sufficient amount of crew to guarantee the safety of the people on board and of the shipping adventure as a whole. If this is interpreted as there should always be crew on board, then autonomous ships of the third and fourth degree won't comply. However, one could argue that autonomous ships can guarantee the same amount of safety without personnel on board and therefore don't have to have a crew.

Article 1.09 dictates that the captain who is steering the ship should always we able to receive information inside the wheelhouse. He must be able to hear and see but can use optical aids when his vision would be blocked. It was already argued that the SCC could be seen as a wheelhouse away from the ship, vessels of the second and third degree would then comply with this article.

Articles 1.10 and **1.11** sum up the documents that need to be on board, just like article 7 of the previous decree. When it comes to these documents, digitalization can be a solution. If police officers need to check the documents, they could then contact the SCC. **Article 1.16** contains provisions regarding salvage and assistance. These were already discussed above in section 4.3.5.

Article 4.06 regulates the use of radar on inland waterway vessels. Radar can only be used by a person with the right qualifications on board the ship. Autonomous ships will all use radar so according to this article they should all have a qualified person on board. This is an issue for the unmanned vessels. However, one could say that having a person with the right qualifications in the SCC is comparable to having him on board. Autonomous vessels of the fourth degree have systems that interpret the radar information and therefore cannot comply and thus need an adjustment of the decree.

4.4.1.3. Royal Decree March 9th, 2007

Table 13. Royal Decree March 9th, 2007 – Scope and problematic articles

Art. 1	6° Vaartuig: een schip of een drijvend werktuig 7° Schip: binnenschip of zeeschip 8° Binnenschip: een schip dat uistluitend of overwegend bestemd is voor de vaart op de binnenwateren
Art. 3	De bemanning die zich aan boord moet bevinden van schepen die de scheepvaartwegen van het Koninkrijk bevaren, dient voor alle exploitatiewijzen in overeenstemming te zijn met de voorschriften van dit besluit. De voor de desbetreffende exploitatiewijze en vaartijd voorgeschreven bemanning moet zich tijdens de vaart voortdurend aan boord bevinden. Het is niet toegestaan zonder de voorgeschreven bemanning te vertrekken. […]
Hoofdstuk V, VI, VII, VIII, IX, Ixbis & XI	Minimumbemanning van schepen

This decree prescribes crew regulations for ships navigating the inland waters of the Belgian Kingdom. **Article 1 (6-8)** determines that this royal decree falls within the scope of this thesis.

The definition of 'ship' or 'vessel' is very broad and would not discriminate against autonomous vessels. The problem lies with article 3 and the crew requirements further in the document.

Article 3 dictates that the crew must be on board when the ship is sailing the inland waters. The crew also has to be qualified according to the standards laid down in this decree. The article also mentions it is not allowed to depart without the required crew on board. Autonomous vessels of the first and second degree have crew on board and would be able to comply with the conditions in this decree. Vessels of the third and fourth degree, however, would not as these vessels use the SCC or sail fully autonomous without any crew on board. The other chapters, **chapter C, VI, VII, VIII, IX, IXbis and XI**, determine the amount of crew that needs to be on board according to the type of vessel and the equipment present.

It is clear that this royal decree needs to be amended to fit autonomous vessels of various degrees if we ever want to implement (fully) autonomous vessels of the third and fourth degree without crew on board.

4.4.1.4. Belgian Shipping Code

Table 14. Belgian Shipping code – Scope and problematic articles

Art. 1.1.1.3.	§1	"Schip": elk tuig, met of zonder eigen beweegkracht, met of zonder waterverplaatsing, dat drijft of heeft gedreven en dat wordt gebruikt of geschikt is om te worden gebruikt als middel van verkeer te water, met inbegrip van luchtkussenvaartuigen doch met uitsluiting van vaste tuigen, watervliegtuigen en amfibievoertuigen
Art. 1.1.1.4.	5°	"Belgische binnenwateren": de van het Belgische grondgebied deel uitmakende openbare wateren die voor de scheepvaart bestemd of gebruikt worden.
Art. 2.1.1.2.	2°	"Kapitein": de gezagvoerder (art. 2.1.1.3. 1°: elke persoon aan wie het bevel over het zeeschip is toevertrouwd of die dit bevel feitelijk en rechtmatig voert) van een zeeschip, met uitzondering van een zeeschip bestemd of gewoonlijk gebruikt voor visserij of niet bedrijfs- of beroepsmatige pleziervaart
Art. 3.2.3.11.	§2	5° De bedragen die aan de schipper en de bemanningsleden verschuldigd zijn in verband met hun werkzaamheden aan boord van het betrokken binnenschip in de haven, met inbegrip van de aan deze personen verschuldigde terugbetalingen van in deze paragraaf bedoelde kosten en van repatriëringskosten;
Art. 4.2.2.1.	3°	Het uitoefenen van de opdrachten van gerechtelijke politie aan boord van schepen en vaartuigen;
Art. 4.2.2.2.		Onderzoeksbevoegdheden […] kan de Scheepvaartpolitie:
	1°	Ten alle tijde schepen en vaartuigen betreden;
	2°	De inzage vorderen van alle zakelijke documenten alsook deze gegevens en documenten kopiëren
	3°	Alle noodzakelijke medewerking van de gezagvoerder van het schip vorderen
	6°	Vorderen dat de kapitein of de schipper van het schip dit doet stilhouden en naar de door haar aangewezen plaats overbrengt

A lot of the previous international conventions and federal decrees have been implemented in the BSC, the Code will be analyzed nonetheless but repetition will be avoided. The focus will be on the inland barges sailing the inland waterways.

Art. 1.1.1.3. and **1.1.1.4.** define the terms 'ship' and 'inland waters', according to these articles the BSC will be applicable to autonomous vessels in inland waterways. **Art. 2.1.1.2.** defines the 'captain' of the ship as the person in charge of the vessel. The article doesn't mention whether or not the captain must remain on board during the voyage and therefore won't be a problem for vessels until the third degree.

Even though the BSC is a lengthy document, not a lot of provisions form a potential problem for autonomous ships. **Art. 3.2.3.11.** contains conditions regarding liens and mortgages and describes the activities performed by captain and crew on board the vessel that fall under the liens and mortgages regime. Will these activities still qualify when they were not performed on board but form a SCC?

Articles 4.2.2.1. and 4.2.2.2. contain provisions regarding the tasks of The Maritime and River Police. These articles don't really pose legal challenges but do raise some practical concerns. The elements **1-3°** describe how the police can enter a vessel at all times, can request access to all relevant documents and can demand the necessary cooperation of the captain. The first concern is that the police will need to have the possibility to contact the SCC at all times. As long as there is a SCC to contact, this won't be a problem. The police can also request full cooperation of the captain but if the captain is not on board this cooperation will be rather limited. Lastly element **6°** states that the police can order the vessel to stop or to divert to a different location. As long as the vessel has an autonomy degree of 3 or lower, this won't be an issue. When the vessel is fully autonomous (degree four), there won't be a captain and the ship will take the decision all on its own. Therefore, a mechanism is needed for fully autonomous vessels and The Maritime and River Police to communicate.

4.4.2. Flanders

4.4.2.1. Royal Decree of September 23rd, 1992

Table 15. Royal Decree of September 23rd, 1992 (police regulations) - Scope and problematic articles

Art. 2	1°	Schip: een drijvend voorwerp, met inbegrip van een voorwerp zonder waterverplaatsing en een watervliegtuig gebruikt, of in staat om te worden gebruikt als middel van verplaatsing te water.
	9°	Kapitein of schipper: degene die over het schip of het samenstel het gezag voert of die het gezag in feite waarneemt.
Art. 3	§1	Geen schip of samenstel wordt op de Beneden-Zeeschelde toegelaten indien het ingevolge de aard of de toestand van zijn voortstuwmiddel of stuurinrichting niet op veilige wijze de stroom kan bevaren.
Art. 21		Iedereen moet van het verdwijnen van boeien of baken of het uitdoven of defecte werking van lichtboeien of -bakens onverwijld en langs de vlugste weg kennisgeven aan […]
Art. 42		Aan boord van elk schip, met uitzondering van een open klein schip, moet aanwezig zijn:
	1°	een bijgewerkt exemplaar van dit reglement;
	2°	een bijgewerkte, meest recente uitgave van de officiële zeekaart van de Beneden-Zeeschelde. Deze moeten op de eerste aanvraag van een ambtenaar belast met toezicht op de naleving van het reglement, ter inzage worden gegeven.

Some regions have their own provisions, the Royal Decree of September 23rd, 1992, dictates the police regulations of the 'Beneden-Zeeschelde' region. According to **article 2, 1°** this decree will be applicable to autonomous vessels in inland waters as the definition of ship is formulated in a broad manner. **Article 2, 2°** defines the captain as the person who has the authority over the ship. The article does not stipulate whether or not the captain should be on board to fulfill this role.

Article 3 §1 stresses the importance of the safety of the vessel. No ship will be allowed on the Beneden-Zeeschelde if it is not capable of sailing these waters in a safe way. This implies that autonomous vessels will need to be tested extensively to make sure they are just as safe as the conventional ships before they can be implemented in the regular shipping business.

A more practical concern is **article 21** which states that everyone should report missing or malfunctioning buoys or beacons to the designated authorities. Autonomous vessels of the fourth degree should therefore have this same ability. The vessels will need all the knowledge and abilities of a regular captain and should be able to communicate as such. Another concern is **article 42** regarding the documents on board the ship. This is a provision we find in several rules and regulations and that will always be an issue in fully autonomous ships. With the changing world and growing digitalization, there should be a focus on online documents. If an official wants to check the documents, they should reach out to the SCC or be able to see the documents online when it's a fourth-degree vessel.

4.4.2.2. *Royal decree of September 23rd ,1992*

Table 16. Royal Decree of September 23rd, 1992 (shipping code) – Scope and problematic articles

Art. 2	§1 1°	Schip: een drijvend voorwerp, met inbegrip van een voorwerp zonder waterverplaatsing en een watervliegtuig gebruikt, of in staat om te worden gebruikt als middel van verplaatsing te water
	§2 a)	Wordt verstaan onder kapitein of schipper: diegene die over het schip of het samenstel het gezag voert of die het gezag in feite waarneemt
Art. 5	Een schip moet te allen tijde door kijken en luisteren alsook door gebruik te maken vanalle beschikbare middelen aangepast aan de heersende omstandigheden en toestanden, goede uitkijk houden zodat de omstandigeden en het gevraar voor aanvaring volledig kunnen worden beoordeeld.	
Chapter II & IV	Provisions regarding diverting and signaling	
Art. 47	§1	Kapiteins en schippers zijn verplicht de aanwijzingen en bevelen van tijdelijke aard op te volgen in bijzondere gevallen, met betrekking tot de doorvaart worden gegeven door […]
Art. 48	Aan board van elk schip, met uitzondering van een open klein schip, moet aanwezig zijn: 1° een bijgewerkt exemplaar van dit reglement; 2° de bijgewerkte, meest recente uitgave van de officiële zeekaart van de Beneden-Zeeschelde. Deze moeten op eerste aanvraag van een ambtenaar belast met het toezicht op de naleving van het reglement, ter inzage worden gegeven.	

Another document regulating the 'Beneden-Zeeschelde' is the Royal Decree of September 23rd 1992 containing the shipping code of this region, a similar decree regulates the fairway Gent-Terneuzen. **Article 2** describes the scope of the document as in the previous decree.

Article 5 dictates that the ship should always listen and watch and make use of all available means to be aware of the surroundings and prevent collisions. It was previously discussed that a ship cannot listen and watch in a human way, but the article clearly states this should be done in addition to using all available means. One could argue that the "available means" of an autonomous vessel are much more advanced than the equipment of a conventional ship. Would the available technology then be enough to replace the human eyes and ears? This provision is only problematic when using autonomous vessels of the third and fourth degree where the crew is no longer on board.

Article 47 §1 imposes the obligation of captain and crew to follow the temporary demands of officials in certain cases. When there is still crew on board this is not an issue, even in a third-degree autonomous vessel communication with the SCC could be established. But what about fully autonomous vessels? How will they communicate with officials and react to orders given? **Article 48** builds on article 47 and states the documents that need to be on board at all times and again gives rise to questions regarding digitalization.

Lastly, **chapter II** and **IV** contain provisions regarding diverting and signaling of vessels in the Beneden-Zeeschelde region. The chapters regulate the behavior in and out of the fairway, prohibit sailing at the same level, dictate what to do to prevent head on collisions, how to react when the course of two ships cross, how a ship needs to divert, the rules of priority on the fairway and sum up the special signals regarding maneuvering and warning. The question is how autonomous vessels of the fourth degree will comply with these parts of the decree. How will they assess dangerous situations and react accordingly? How will they carry out the different signals?

4.4.2.3. Law of March 15th, 2002

The law of March 15th, 2002 contains the regulation for the specific region of the Common river Meuse and was based on an agreement of January 6th, 1993[28] between Belgium and The Netherlands. Even though the law contains provisions that could be problematic for inland navigation by autonomous vessels, it won't be discussed in detail as the Common Meuse is not accessible to ships. Smaller vessels like pleasure yachts can use the Common Meuse but fall outside the scope of this paper (De Vlaamse Waterweg, n.d.).

4.4.2.4. Collective Decree of January 19th, 2022

Table 17. Collective Decree of January 19th, 2022 – Scope, problematic articles, and modifications

Art. 2	3°	Binnenschip: een schip dat uitsluitend of overwegend bestemd is voor de vaart op binnenwateren, met inbegrip van een estuair schip; de teboekstelling van het schip in een register van binnenschepen geldt als vermoeden dat het schip een binnenschip is
	4°	Binnenwateren: de openbare wateren in het Vlaamse Gewest die voor de scheepvaart kunnen worden gebruikt, […]
Art. 45		In geval de gezagvoerder van een schip een hindernis in de door een waterwegbeheerder beheerde waterweg aantreft of kennis krijgt van de aanwezigheid van dergelijke hindernis in die waterweg, geeft hij daarvan onverwijld kennis aan de waterwegbeheerder […].
Art 52		De Vlaamse regering bepaalt de documenten die ingevolge dit decreet aan boord van het schip voor inzage beschikbaar moeten zijn en stelt de nadere regels hieromtrent vast. De Vlaamse regering kan eveneens voorzien in vrijstellingen voor bepaalde categorieën van schepen
Art 69	§1	De waterwegbeheerder of het havenbedrijf kan toelating geven voor het uitvoeren, binnen het gebied dat de waterwegbeheerder of het havenbedrijf beheert, van experimenten of pilootprojecten, waaronder het uitvoeren van proefreizen, waarbij gebruik wordt gemaakt van innovatieve systemen. Dergelijke systemen omvatten onder meer geautomatiseerde systemen in vaartuigen of aan wal […].
	§2	Bij de toelating voor de experimenten of pilootprojecten als vermeld in paragraaf 1 worden in ieder geval de volgende zaken bepaald: […].

[28] Overeenkomst van 6 januari 1993 tussen het Konkrijk België en het Koninkrijk der Nederlanden tot regeling van het scheepvaartverkeer en van de recreatie op de gemeenschappelijke Maas

The Collective Decree of January 19th, 2022 presents a new shipping decree regarding the use and management of the inland waterways in Flanders. The new decree takes into account the changing world with new technologies and possibilities and the international framework. **Article 2** confirms this decree falls within the scope of the paper.

Article 2, 3° dictates that ships meant for inland navigation should be registered in a designated register. Will autonomous inland vessels be registered in this same register, or will they have a separate one? Creating a separate register for these vessels is potentially a very extensive administrative task in inland navigation and will probably be avoided if possible. Another option is adding them to the register with a special indication emphasizing the ships are autonomous.

Article 45 corresponds with article 21 of the Royal Decree of September 23rd 1992. The captain or shippers must always report obstacles or broken infrastructure to the designated official. When there is still crew on board (first or second degree of autonomy) or there is a continuous connection to the SCC, this won't be a problem. But what will autonomous ships do when they come across an issue? Will there be a direct link to the institution managing the waterway?

Article 52 was drafted to accommodate the increasing digitalization. It was mentioned before that keeping documents on board won't always be a possibility when dealing with autonomous vessels (cfr. no wheelhouse). The article has changed the wording by stating that the documents that normally have to be on board the ship "should be available for inspection at all times". Some type of vessels might be exempted from this requirement, but it is not clear what kind of vessels are meant in this article.

Article 69 was introduced to enable experiments and pilot projects regarding new technology. The testing of autonomous vessels is explicitly mentioned in this article. **Art.69 §2** describes the conditions to start testing, these correspond to the testing procedure mentioned in section 3.2.2.1.

Eventually there will be a need for a framework regarding autonomous shipping. Whether this will be a separate framework, or if the regulations will be integrated in the current legal framework, will be decided by the Flemish government. They will then take into account the results of the test that are presently being done (see section 5).

5. (Belgian) Projects

This section will discuss two Belgian pioneer projects as well as a European project with Belgian involvement: Smart Shipping, Seafar and AUTOSHIP.

5.1. Smart shipping

‘Smart shipping’ is a Belgian project created by the Flemish Waterway nv to respond to the shortage of skippers on inland barges (De Vlaamse Waterweg, n.d.). This shortage means that the smaller vessels are disappearing, and the smaller waterway fall into disuse. When the smaller waterways are not being used, it becomes harder to compete with road transport resulting in a reverse modal shift; cargo is brought back from waterway transport to road transport. This will result in even more congestion and emission of greenhouse gasses. Automated vessels are identified as a possible solution to these problems and would revive inland waterway transport.

The Flemish waterway nv has started the Smart Shipping Program to enable the future of automated sailing. They are taking a pioneering role by creating attention for autonomous vessels and are paving the way for companies to invest in autonomous shipping and contribute to a future where autonomous vessels can be used for commercial purposes. The Smart Shipping Program is based on four pillars. Smart vessels, smart infrastructure, smart data, and smart regulations (Pauwelyn, n.d.).

First, a *smart vessel* refers to a vessel which has a minimal form of automation and is equipped with automated systems that uses (external) data to optimize the key functions of the ship. The degree of automation is of no importance. The automated vessel must, however, be able to guarantee the same safety level as a regular ship. The definition of a smart vessel resembles the definition given to MASS by the IMO (Pauwelyn et al., n.d.; De Vlaamse Waterweg, n.d.).

Smart infrastructure (and traffic management) entails a waterway infrastructure that is highly automated and remotely operated. In order to have safe traffic in inland waterways, the interaction between vessel and infrastructure takes place digitally and is based on real-time (external) data. There needs to be a connection at all times, which is a problem we will discuss in the section ‘Other challenges’ (Pauwelyn et al., 2018).

Smart data is sharing data in a smooth, quick, and flexible way. The communication between the government and inland vessels needs to be digitalized and up to date with the internationally standardized procedures. Cyber security needs to be considered as the communication between the automated vessel and the SCC needs to be secured at all times (Pauwelyn et al., 2018).

Lastly, *smart regulations* refer to regulations that support innovative and future-oriented initiatives that take into account safety, environmental issues and cost efficiency. There needs to be a smooth and continuous communication between stakeholders regarding regulation and inspection (Pauwelyn et al., 2018; Pauwelyn, n.d.; De Vlaamse Waterweg, n.d.).

Due to the introduction of the Decree of April 26 (2019) and the Collective Decree (2022) the Flemish Waterway nv was able to open up the Flemish waterway network (see figure. 2) as a testing area for vessels with a certain degree of autonomy. The test can only be permitted by the Flemish Waterway nv after a formal request has been made following the procedure described in the previous section.

Figure 2. Testing area autonomous shipping in Flanders (De Vlaamse Waterweg, n.d.)

5.2. Seafar

Seafar is a company located in Antwerp and specializes in remote ship management and crew-reduced navigation through a shore support center. By integrating new services and technologies, shipping companies and operators can continuously increase their operational efficiency. Ship management and shore supported navigation can reduce the operational costs by working with a reduced crew. The technology can enhance competitiveness and expands the navigational possibilities. Ships can now expand the hours of navigation without adding additional crew and increasing the labor costs. As mentioned before a ship could gain over 500 hours of operational hours yearly by introducing the Seafar technology. In short, Seafar offers the service to operate vessels from a SCC, to increase efficiency by reducing crew on board (Cool, n.d.).

For now, Seafar is focusing on inland shipping. The first problem they are trying to address by creating and implementing new technology is the crew shortage. Many young skippers don't want to be away from home for extended periods of time. This technology could turn a three-week onboard operation into a 40-hour workweek with eight-hour shifts in the SCC. A crew shortage could mean a limitation when it comes to the growth of the fleet and the competitiveness per vessel. Seafar is also committed to contribute to a new green fleet. The shortage of personnel and high operational expenses call for a new approach which is being implemented by the Seafar technology and services (Seafar, n.d.).

The Seafar Control System is an in-house system which is integrated with all onboard systems. The hardware and software are being engineered by Seafar and can be integrated on existing vessels or new built projects. Seafar produces the control and communication system as well as the sensor architecture (see figure. 3)(Cool, n.d.).

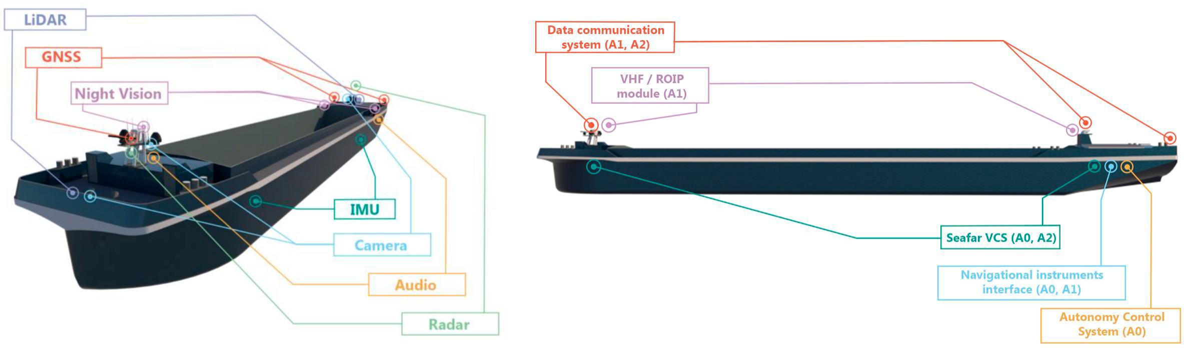

Figure 3. Control system, communication system and sensor architecture on inland vessels with Seafar technology (Cool, n.d.)

The captain, working from a SCC at a Seafar site (see figure. 4), navigates via direct or automated control under supervision. The captain has a range of tools and technologies which he can use to ensure a safe operation at all times. All the onboard functions are available remotely, but there is still a crew onboard which supports the remote captain for technical and safety purposes.

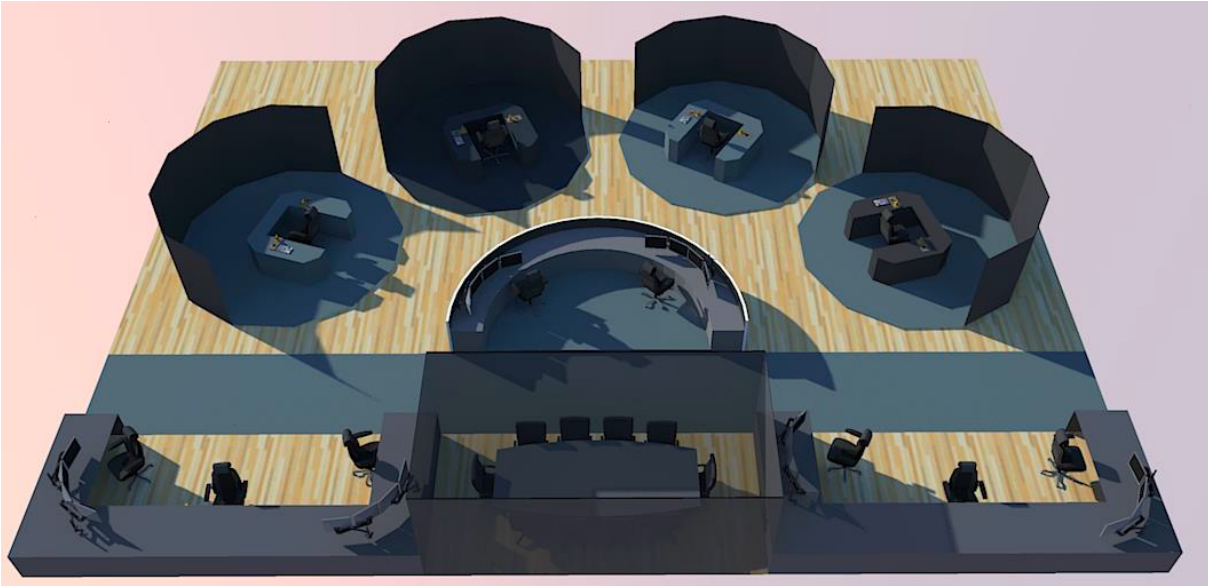

Figure 4. Lay-out shore control center (Cool, n.d.)

By using technology as a toolbox, this company is able to transform the navigational operation with command and control software reinforced by the latest A.I. to ensure safe operations. The combination of vessel autonomy for navigation and remote pilotage, as well as for support in manoeuvres, is key for the implementation of efficient smart shipping. The vessel navigates autonomously and collects data during the whole journey (Cool, n.d.). When the sensors detect a problem like a lock, a narrow passage, another vessel or kayaker, the program sends a warning signal to the captain. The captain then takes control over the vessel, like he would when he is physically on board, and steers the vessel through the situation (L-R. Cool, pers. com., 2022, March 9).

Apart from improving the current technology, Seafar is also thinking about the future. They are looking into optimizing capital and operational expenditures, hybrid ships running on dual fuel and diesel-electric ships (Cool, n.d.). Furthermore, on January 21 RensenDriessen Shipbuilding announced the start of the construction of 10 semi-autonomous ships, 'river drones', using the Seafar technology in order to diversify the fleet (Seafar, 2022).

5.2.1. Handling regulatory gaps

Due to the new regulatory framework, testing in Flanders is allowed and Seafar is taking advantage of this with various vessels already sailing the Flemish inland waters. Testing in Wallonia is not officially allowed as they don't have a testing procedure in place, but there are agreements with the Flemish Waterway resulting in a tolerance policy based on a federal framework. In other countries, e.g. Germany, testing is being done with a full crew on board to comply with the country's rules regarding shipping (L-R. Cool, pers. com., 2022, March 9).

5.3. International projects - AUTOSHIP

AUTOSHIP stands for 'Autonomous Shipping Initiative for European Waters' and aims at speeding up the transition towards a new are of autonomous shipping in the EU. Autoship will show owners how they can improve the economies of scale of their investment, how to effectively gain competitiveness and the possibility of replacing road transport (Autoship, n.d.).

The project consists of two different autonomous vessels, one for short sea shipping and one for inland waterways, both focus on the mobility of goods and automated vessels as means of transportation (Autoship, n.d.) The short sea shipping demonstration will take place in Norway using the Eidsvaag Pioneer owned by the Eidsvaag shipping company. The vessel will carry fish feeds to the different fish farms located along the Norwegian coast (Midtbø, 2020).

The demonstration for inland waterways will take place in Flanders with a pallet shuttle barge by the Belgian company Blue Line Logistics. The vessel will transport goods between large container ports and will show the environmental gains of autonomous shipping by replacing 7500 trucks yearly (Midtbø, 2020). During this demonstration there won't be any crew on board, the ship will be fully controlled by a SCC (De Vlaamse Waterweg, n.d.).

The goal is to use the results of these demonstrations to fill in the gaps regarding legislation, safety, socio-economic factors and (cyber-)security. The project wants to test and ameliorate the key technology used in autonomous navigation systems, intelligent machinery systems, self-diagnostics, prognostics, and operation scheduling as well as test the communication technology and its security (Midtbø, 2020). The project wants to deliver a roadmap, standards and methods for future adopters and developers and help them commercialize autonomous vessels. The demonstrations are expected to be complete at the end of 2022 (De Vlaamse Waterweg, n.d.).

6. Other challenges

The autonomous ships that are being tested and used today have found a way to get around the legal challenges, but there are some other challenges that need to be considered when talking about the future of autonomous shipping. Safety, connectivity, infrastructure, human behavior, and costs need to be taken into account when designing the ships, ports and waterways of the future. In reality these challenges are intertwined but they will be discussed separately.

6.1. Safety

Even though it is said that autonomous shipping will increase safety, it will also introduce new types of accidents (Aslam et al., 2020; Montewka et al., 2018). To fully implement autonomous shipping in the transport sector, the MASS need to be at least as safe as the current conventional vessels (Hoem et al., 2018). Safety can cover many grounds like cyber security, safety of the crew, safety of the surrounding ships etc. (Kim et al., 2020).

Wróbel et al. (2019) have showed that navigational risks like stranding and collisions may decrease but non-navigational risks such as fires, flooding and explosions are likely to increase. Also, since MASS rely heavily on software and connectivity a cyber security risk is inevitable. The use of information technology systems onboard and onshore will cause a vulnerability for cyber-attacks that is far greater than in conventional vessels. It is possible that MASS will create new possibilities for pirates, terrorists, and other criminals (Kim et al., 2020; Komianos, 2018). Komianos (2018) lists the potential risks following the introduction of MASS (see Table 18.)

Table 18. Potential risks MASS (Komianos, 2018)

Risks	Example
Rise of cyber-security threats	Hacking attacks to abduct the ship and hijack cargo (piracy)
	Leaking of sensitive information
Failure of equipment	Failure of key operation systems causing the failure of the ship
	Failure of communication systems
Error or distortion of information	Distortion of information communication with SCC
Difficulty of recognizing accidents	Failure or delay of SCC to recognize the situation
Challenge of cargo management	Cargo on fire
Threat against port security/infrastructure	Weaponization of autonomous ships

As shown in Table 18, there is a risk that cyber pirates remotely hijack a MASS, with the intention of asking a ransom to release the vessel (Murray, 2019). A second major fear is terrorists hacking ships and using them as a weapon to kill passengers and/or destroy port infrastructure (Vinnem & Utne, 2018). The last concern is the safety of information transferred from the ship to the SCC and back. The connection might be hacked and information might be changed which would cause problems for the unmanned autonomous vessel. Also document based systems should be extra secured as the integrity and authenticity of documents such as the bill of lading, certificates etc. must remain intact. This will be discussed further in the sections below (Rødseth et al., 2020).

Therefore, safety assessment before designing, building, and implementing is of upmost importance (Kim et al., 2020). The IMO (n.d.) offers two risk assessment instruments, the Formal Safety Assessment (FSA) and the Global-based standards (GBS) (Montewka et al., 2018). The FSA is described as "a rational and systematic process for assessing the risks associated with shipping activity and for evaluating the costs and benefits of IMO's options for reducing these risks". GBS relates to "high level standards and procedures that are to be met through regulations, rules, and standards for ships. GBS are comprised of at least one goal, functional requirement(s) associated with that goal, and verification of conformity that rules/regulations meet the functional requirements including goals" (IMO, n.d.).

6.2. Connectivity

In order to have efficient and safe operations, a critical component for an unmanned and autonomous ship is a wireless communication system (Höyhtyän et al., 2017). However, connectivity is a challenge as it is not always a given, multiple wireless systems are needed to secure communication needs (L-R. Cool, personal communication, 2022, March 9; Höyhtyän, 2017). Autonomous ships today rely on a SCC to assist the vessel in case of problems, but what if connection fails and the vessel is on its own?

The extent of the connectivity problem depends on the operational environment; inland navigation will have less problems than deep sea operations (Höyhtyän et al., 2017). For inland shipping, vessels will rely on terrestrial solutions. LTE and 5G will have the capacity to support LIDAR and video data transmission with regular updates. Deep sea operations, however, will have to rely on other means such as satellite systems, high altitude platforms and long-range terrestrial systems. These systems all have limits which will need to be addressed before full deployment of autonomous shipping on the open seas (Aslam et al., 2020; Höyhtyän et al., 2017).

Autonomy must be implemented to make sure a ship can operate without needing SCC to continuously control the ship (Rødseth et al., 2013). It is very important that essential ship data such as collision detection and situational awareness data, data regarding safety systems and machinery can be processed onboard without human intervention. Another issue is that the line between vessel and control center must be secured at all times. The communication system is an integral part of the safety system and will require certification (Höyhtyän et al., 2017).

The most worrisome threats regarding autonomous ships' communication and connectivity are losing the data, having the data changed and hijacking the data that is communicated. As mentioned in the 'safety' section, good coding and cyber security protocols and mechanisms need to be put in place to prevent these threats from happening. An important safety element regarding connectivity is a fail-safe procedure, a procedure that dictates what happens when connection is lost (Höyhtyän et al., 2017). For example, the vessels described in the Seafar project have a built-in safety mechanism, when the connection is lost, the vessel shuts down and remains in place until the connection is restored (J. Goderis[29], pers. com., 2022, March 9).

A good connectivity will make for an 'Internet of Ships' where ships, cargoes, the waterway environment, and shore-based facilities are all interconnected. These components could then collect and exchange data in real time resulting in safer operations (Aslam et al., 2020). For now, remote operation is not possible in all geographical areas. Technology today makes it possible to operate remote controlled/unmanned vessels close to shore, inland or in port areas, but technology to operate at open seas is yet to be developed (Poikonen, 2018).

6.3. Infrastructure

Increased automation also requires an increase in 'digital trust' as humans will be less and less needed in the information processing loops. With increased digitalization new challenges like issues with cyber security will arise. Ship documents like certificates and electronic port clearance but also cargo documentation, are becoming part of the digital information exchange. There is a need for an ICT infrastructure that supports this evolution. Scholars therefor present a Public Key Infrastructure (PKI) or the blockchain as a possible solution to raise security barriers and mitigate cyber threats. These PKIs need to be designed with a certain shipping

[29] Jan Goderis is the COO of Seafar, a company that supports and operates automated vessels from a SCC. The vessels are integrated with a Seafar Control System and are operated by a licensed captain. Seafar is the first company in the world to realize commercial automated shipping.

business in mind as the lack of connectivity, network technologies, regulatory considerations and communication systems depends on the nature of the operation (Meland et al., 2019; Rødseth et al., 2020).

PKI need to be introduced due to three main issues. First, there is a real possibility of cyber-attacks for commercial gain or to inflict damages. Secondly, there is an inherent distrust in automated processes which results in manual double checking, this can be reduced using PKI. Lastly, when skippers eventually leave the ship and it functions without crew on board, the information evaluation and decision-making process needs to be correct and trustworthy (Rødseth et al., 2020).

A function of the PKI is the ability to create, store and distribute cryptographic keys amongst users that need to communicate over a secured line so they can exchange critical information in a safe manner (Meland et al., 2019). It can also be used to digitally sign electronic ship certificates, logbooks, bill of lading etc. When both parties are part of the PKI is it easy to verify the authenticity of messages and documents as it is an option that only the owner of another private key can open and read them (Rødseth et al., 2020).

Just like PKI, blockchain uses public key cryptography to add timestamps to transactions and cannot be altered without the agreement of all partners. Blockchain is thus very useful when documents need to be exchanged. The advantages of blockchain are the decentralization, persistency, anonymity, and auditability of the system. Which system should be used depends on the purpose and the environment in which they have to operate (Meland et al., 2019).

As mentioned before, cyber-attacks could have an influence on the physical infrastructure of the vessel, ports and waterways. Scholars are particularly worried the hacked vessel could be used as a ram and become a cyber security weapon used to attack other vessels (Press, 2017; Vinnem & Utne, 2018). If there is a crew on board of the other vessel, they should be able to avoid the attack, but stationary infrastructure installations can't be relocated in case of a threat. In this case autonomous vessels could be used, for example, to destroy bridges or damage port infrastructure. Reenforcing the infrastructure is not an option due to excessive costs. The focus needs to lie with prevention which brings us back to cyber security (Vinnem & Utne, 2018).

6.4. Human behaviour

With the rise of autonomous shipping there has been a lot of speculation regarding the future role of seafarers and skippers. Research by the Hamburg School of Business Administration (HSBA) (2018), commissioned by the International Chamber of Shipping, has shown that 84% of maritime professionals believe that autonomous shipping could be a threat to their job in the future (Nautilus international, 2018). The research focussed on the potential social and practical consequences of increased digitalization and autonomous shipping on seafarers (HSBA, 2018).

While it was found that automation will not lead to job losses, a shift in approach was predicted. A 'hybrid' system of 'smart' systems and trained seafarers was suggested, seafarers remain in control while being supported by 'smart' systems. Experienced seafarers will be deployed in shore-based jobs where a successful career is determined by the time spent on board a vessel, the need for qualified seafarers will thus not decline. Automation will therefore create new but different jobs with a strong bias to the extreme ends when it comes to qualification, more low-skilled and more high-skilled jobs will be created (HSBA, 2018). Guy Ryder, the Director-General of the International Labour Organization (ILO), expects a turbulent period which will eventually result in more and better-quality jobs with a higher living standard (Loctier, 2018).

Even though there would be no expected job losses, Adamson (2018) fears a decline in mental health. The number of people on board will inevitably decline and their functions will be taken by machines and systems. This will lead to less social interaction, loneliness and potentially depression. De decrease in crew could also affect the minimum safe manning according to recent studies (HSBA, 2018). These worries were rebutted by Allal et al. (2017), they say autonomous shipping will have a positive social impact as seafarers will be home more often.

Crews on board will shrink with the rise of autonomous vessels, the number of officers will remain the same whether it is on- or off-shore and the number of crew on shore taking care of supporting functions will increase. Therefore, there will be no shortage in jobs for seafarers in the future, on the contrary, jobs ashore will increase. However, seafarers will need to be retrained to deal with the increased digitalization and sometimes lonely situation on board (HSBA, 2018).

6.5. Costs

It was already mentioned that autonomous shipping will have a cost related impact and will be more profitable for ship owners in the long term. Reduced crew related costs and the increased fuel efficiency will make for a reduction in the operating and voyage costs (Ziajka-Poznańska & Montewka, 2021). However, there are costs that current research hasn't taken into account. What about insurance, increased cyber security, the design and maintenance of the SCC, emergency arrival of crew on board, shore- and port-based services, building costs… The answer to these questions will depend on the type of vessel, the cargo, the flag state etc.

Autonomous vessels will involve new challenges regarding Protection and Indemnity insurance (P&I) as they differ on many levels from conventional ships. New risks have been created as well as new definitions and roles (Southam, 2020). P&I clubs cover the third-party liability, among other things, but mainly cargo liabilities, crew claims, damage to property, collisions, and wreck removal… (Bennet, 2000). Most claims relate to human errors which will be heavily reduced by the introduction of autonomous shipping, leaving the claims regarding cargo, ship, and pollution. P&I clubs largely rely on legal frameworks, case law and best practices to conduct a risk assessment, however these are not yet in place when it comes to autonomous vessels. The risk with regard to collisions of autonomous and conventional vessels, cyber security and on shore crew are relatively unknown for the moment. A detailed risk assessment is thus not possible at this time due to the lack of reliable data (Southam 2020; Ziajka-Poznańska & Montewka, 2021).

There is however a first insurance policy for autonomous ships in Belgium and according to Kristof Olyslager, one of the brokers that helped create it, the policy is not more expensive than the insurance policy of a conventional ship. It is expected that autonomous vessels will result in a safer shipping environment and less accidents by reducing human errors and will thus lead to cheaper policies in the long term. The main challenge is finding an insurer who is willing to take a leap and insure an autonomous vessel (K. Olyslager, pers. com., 2022, April 5).

Another extra cost will be the enhanced cyber security set-up. Considering the advanced navigation software and equipment onboard autonomous vessels, cyber security is a serious concern and needs extra investments to prevent infringements (Bauldrick, 2019). A lot of systems are begin developed to reduce the risk of a cyber-attack to a minimum (Tam & Jones, 2019). The cost of these systems, training of IT personnel and the needed infrastructure will depend on the type of operation. Current research hasn't put a number on this kind of investment.

Currently autonomous vessels rely on an onshore captain taking over control in difficult situations, this captain is located in a SCC. The design and maintenance of these SCCs is also a cost that needs to be taken into consideration. The investment cost of developing a SCC is estimated to range from 1 to 2.1 million USD (0,9 to 1,9 million euro), depending on the size of the operation and the vessels that needs to be controlled. The annual operation and maintenance cost will be around 0.87 million USD (0,79 million euro). The operation of the vessel from the SCC will cost on average 33,000 USD (30 000 euro) per vessel per year, again depending on the type of vessel. Shore- and port-based services are an additional cost which is not included in these estimations. Adding to that, the cost of building a new autonomous vessel, depending on the type, will be 32% higher than the cost of building a conventional ship, while the return of the autonomous vessel is estimated to be the same as that of the conventional vessel (Ziajka-Poznańska & Montewka, 2021).

Ideally an autonomous ship will sail without any crew on board, but what happens in case of an emergency? What are the additional costs of having an emergency crew on board? Unfortunately, there is no data available regarding this concern (Ziajka-Poznańska & Montewka, 2021). For example, if there is a fire on board the automated sprinkler system will activate, but if this system is not able to extinguish the fire and the fire department is not on time or cannot reach the vessel, the ship will be lost (J. Goderis, pers. com., 2022, March). To put it very simplistically, the cost of a severe emergency that can only be resolved by onboard crew is the cost of a total loss and all its financial consequences.

Whether or not these costs are comparable to the costs of a conventional ship falls outside the scope of these thesis, but this section does give a good impression of the extra costs that need to be taken into account when designing, building and operating an autonomous vessel.

7. Recommendations

In the previous sections obstacles and gaps that prevent autonomous shipping from being implemented on inland waters today, were identified. Based on these findings a few recommendations can be made.

7.1. Create a legal framework

The Collective Decree applicable to the Flemish region in Belgium is the first decree to enable the testing of autonomous vessels in inland waterways. Even though it is a huge accomplishment and step forward to amend the law, two articles in a decree won't help the entire autonomous shipping sector. The companies involved in R&D are rather small and are not keen on taking risks when there is no legal framework to rely on. Amending all problematic articles would require a huge effort and would be very time consuming.

It is therefore recommended to create a separate legal framework adjusted to the different levels of autonomy as autonomy level one and two will require less adjustments than level three and four. Especially provisions regarding the amount of crew required, technical requirements regarding the construction of the vessel (cfr. the bridge etc.) and liability should be amended and clarified. Another recommendation is for neighbouring countries to perform the same gap analysis and then form bilateral agreements to amend boarder related issues and expand the testing area.

7.2. Define the concept of autonomous vessels

The legislation that was examined in section 4 gives various definitions of vessels and ships, but never defines the concept of autonomous inland vessels. This is not strange as most of the legislation was created at a time where autonomous vessels were merely a concept or idea for the distant future. The more recent Collective Decree which enables testing doesn't define autonomous vessels either, this can be considered as a missed opportunity. The definitions used are very broad so they could also include autonomous vessels, but seeing as these vessels are very different from conventional ships, a separate definition or mention in the legislation is a must.

7.3. Captain and crew on shore

The main legislative issue is the fact that most legal documents require the captain and crew to be on board while navigating. In most cases it is even a condition for the ship to be allowed leave the port. Autonomous vessels of the first and second degree will have a crew on board but vessels of the third and fourth decree will be completely crewless. A vessel of the fourth degree won't even have a captain navigating the ship from a SCC.

Especially the Royal Decrees of October 25th 1935, September 23rd 1992, September 24th 2006 and March 9th 2007 are problematic as they require a certain amount of crew to be on board before the ship is allowed to sail. When it comes to international legislation, the Collision Convention, COLREGs, CEVNI, Salvage Convention, CMNI and ADN need to be amended. These legal documents imply the captain and crew need to be on board to be able to hear and see their surroundings and help other vessels in distress.

Legislation needs to be amended to fit autonomous vessels of the third and fourth degree so they can navigate with a reduced navigational crew or no crew at all. It should also be clarified what the consequences are of removing the captain from the vessel and putting him behind the controls in a SCC. Another exercise is determining what happens if the vessel is completely autonomous and no captain is involved?

7.4. Create a legal framework regarding liability

There can be discussion about who will be held liable when the captain and crew are not on board the vessel when an incident occurs (degree one to three). When there is still a captain navigating from a SCC one could argue that the rules concerning responsibilities and liabilities remain the same. The real problem lies with the fully autonomous vessel with an autonomy degree of four.

There is a need for a clear framework regarding liability that can encourage companies to focus on fully autonomous vessels by reducing the risk and uncertainty. In light of this framework the Collision Convention, Salvage Convention, CMNI and CLNI should be amended to fit the absence of the captain and crew on board.

7.5. Improve communication

To guarantee the same level of safety as conventional ships, autonomous vessels need to have a stable connection to communicate with the SCC. Even fully automated vessels will need to have a way of communicating with the SCC, waterway authorities and the police to comply with regulations regarding their obligation to report missing or damaged buoys etc. When authorities want to control a vessel or if the vessel is in distress, communication is key.

It is therefore recommended to the government to invest in a better network up and around inland waterways to guarantee an uninterrupted connection and way of communication with the vessel during the entire voyage. Especially the more remote areas close the Walloon region should be more connected.

7.6. In case of emergency

Several conventions dictate that the master or boatmaster has the duty to render assistance to any person or vessel in danger of being lost. The conventions put the responsibility of helping vessels in distress on the person of the captain. When the captain is located in a SCC, they will be able to help by notifying the designated authorities. When there is no captain on board the fully autonomous vessel, the vessel will have to be able to recognize a vessel in distress and communicate with the authorities.

It is recommended to rephrase the wording in the Collision and Salvage Convention as well as in the CEVNI to fit autonomous vessels of the fourth degree. It is better to place the duty to assist with the vessel, the ship should then provide aid to the best of its capabilities keeping the limits of the technology in mind. Another recommendation is to test fully autonomous vessels in various distress situations so they can learn how to recognize and help a ship in need.

7.7. Digital documents

For now, the shipping industry is still following the historic way of thinking by using paper-based methods to transfer documents. This is also the case when it comes to documents related to the ship. CEVNI, ADN, The Royal Decree of September 24th 2006, The Belgian Shipping and the Royal Decrees of September 23rd 1992 all state that certain documents should be on board and must be available for inspection at all times. Autonomous vessels of the third and fourth degree won't have any crew, nor will they have a wheelhouse or other crew related constructions. It would therefore be difficult to have the paper documents on board and always ready for viewing.

Considering the current digitalisation, the shipping industry should start digitalizing its documents. This not only preferred in the context of autonomous shipping but in the entire business. If an autonomous vessel is controlled by the waterway police, for example, they should be able to contact the SCC and inspect the documents "on board the vessel". The Collective Decree of January 19th 2022 has accommodated this issue by writing the documents "should be available for inspection" and not "the documents should be available on board". This has made it possible to accept electronic instead of paper documents.

7.8. Technical requirements

ES-TRIN currently regulates the technical requirements for inland navigation vessels. The document states that every vessel should have a wheelhouse, accommodation, fuel-fired cooking and refrigerator equipment and on-board sewage treatment plants. (Fully) autonomous vessels won't have these constructions as there won't be any crew on board. By removing these elements costs can be saved in various areas. Construction and design will be less expensive, fuel consumption will be less as the inland vessels will be lighter and the overall capital cost will be reduced.

It is therefore advised to create different technical requirements for autonomous vessels of the third and fourth degree. The focus should be on standards regarding new technology and advanced equipment as autonomous vessels differ enormously from conventional ships in that respect.

8. Discussion

The above-mentioned results, conclusions and recommendations were formulated after an extensive literary review and gap analysis. Even though the research was done following a well-considered plan and method, a few remarks can be made regarding the result achieved.

Starting with the introduction, definitions, and demarcation of the scope of the paper. There is plenty of research regarding autonomous vessels, all with a different approach regarding definitions and autonomy levels. A decision was made to follow and use the IMO scoping exercise to define the concepts used. Even though their research was focused on MASS and not inland vessels, their findings are still considered to be relevant. The IMO is a highly ranked United Nations organization with experts from all over the world who reached a consensus regarding the autonomy levels of autonomous vessels. We also discussed the perspective of certain scholars to demonstrate that there were various definitions, even before the IMO classified the different levels. As defining terms and concepts determines the scope of the paper, this is a first limitation.

Secondly the overview regarding autonomous vessels contains a non-exhaustive timeline of key events and projects. Norway and Korea are very invested in the research and development of autonomous shipping and therefore have more projects than shown in section 2.2. The projects discussed were the most innovative at that time. It must be said that it is still a very impressive list considering the idea was first mentioned in the seventies. When discussing the need for autonomous vessels, the shortage of skippers is one of the main reasons to switch to autonomous vessels when possible. But maybe it is also an idea to research why the industry is not attractive anymore and try to remediate these push factors as autonomous vessels won't be able to solve the entire shortage. Another remark can be made when it comes to the increased safety of autonomous vessels. There is no available data on inland shipping accidents so the research regarding accidents and increased safety was based on rather dated (1976-2002) research of sea going vessels. The onboard equipment has since become more advances and safety measures have become stricter. The decrease in shipping accidents could also be partially attributed to that and not just to the use of more automated systems. In the section regarding cost reduction the insurance was not taken into account, but it was found that the insurance of an autonomous vessel would be cheaper than a conventional vessel. The price of the increased cyber security and emergency arrival could not be found.

The scope of this paper is inland autonomous vessels but cost reduction by using autonomous vessels could also impact conventional vessels. Akbar et al. (2020) raised the idea of using autonomous vessels as daughter ships for conventional vessels and thereby reducing the operating cost of the mother vessel with 11%. The autonomous vessels could then be used as barges in the smaller ports. This is a good solution as cost reduction due to a decrease in crew is smaller in seagoing vessels and the international regulations are more extensive in comparison to inland vessels.

A third remark can be made regarding the legal framework applicable to autonomous vessels in inland navigation. Due to the complex structure of the Belgian state, there is an abundance of conventions, decrees, laws etc. that can influence the development of autonomous vessels. The legal framework described in section 3 gives a non-exhaustive list of applicable legislation that is most relevant when it comes to Belgian inland waters. There are so many documents available, and it is not always clear whether they are still applicable or not or whether they were amended or replaced. Since all Walloon laws and regulations are in French, these were not included in the paper. However, we do not expect them to bring new insights as the same issues come back in every consulted document. Lastly, a comment can be made regarding the test procedure that is used in Flanders. There is a Flemish procedure but when the Walloon authorities were contacted, they informed us that there was no Walloon equivalent. One could assume that the Flemish waterway could cooperate with the Public Service of Wallonia to expand the testing area. There can be various reason why the Walloon region hasn’t reached the point of testing yet. Number one is geography; the Walloon region is less flat than Flanders which hinders the use of autonomous ships as there are more locks that need to be taken into account. Another possibility is their increased interest in other modes of transport like rail.

The legal challenges were the results of a gap analysis based on section 3. The findings of other scholars were also discussed but this research was not focused on Belgium and were therefor rather broad. This section clearly showed the biggest legal issues regarding the implementation of autonomous vessels, but a lot of questions remained unanswered. For example, there is a huge focus on safety and the prevention of accidents in autonomous inland shipping but what if an accident does occur? There is no liability scenario comparable to conventional vessels.

The Belgian projects are sailing through the legislative hurdles to identify gaps and are adapting to overcome them. Even though the projects don't use fully autonomous vessels, the data they are collecting is very relevant when it comes to future developments.

The other challenges that were mentioned in section 6 were briefly explained to give an overview of other possible challenges that need to be overcome before autonomous vessels can be fully implemented in inland navigations. These topics could present opportunities for future research papers as they are all equally important to the legal challenges.

9. Conclusion

The world is changing, and advanced technology is taking over everyday (simple) tasks, this is no different in the shipping industry. Ever since the seventies, researchers have been looking for a way to make vessels self-steering, or at least remotely controlled. Projects were developed to create intelligent ships and autonomous unmanned vessels. These vessels would solve issues regarding the harsh work environment and consequently the shortage of skippers and crew. They would increase safety using more autonomous systems and automation and would reduce emission due to slow steaming and alternative fuels. Lastly, they would be more cost effective by reducing operational, voyage and capital costs resulting in a more profitable venture for shipping companies.

This thesis focussed on these autonomous vessels in inland waters in Belgium and more specifically Flanders. During this research it became clear that Flanders is a frontrunner in autonomous shipping in inland waters, mainly driven by the prospect of a large shortage of skippers in inland waters in the future. Flanders was also specifically mentioned in the PIANC report of March 2022 because of the legal framework they created to enable testing of autonomous vessels in Flemish inland waters. These tests will identify issues and gaps that need to be overcome, the main gap being the legal framework.

A non-exhaustive overview of (inter-)national legislation showed the abundance of applicable rules and regulations in which autonomous vessels must find a place (see section 3). To be able to grasp the extensity and complexity of this exercise a gap analysis was preformed to identify articles that could pose a problem for autonomous ships of a certain degree. Scholars agree that situations regarding liability, the role of the master and on-board crew, emergencies, insurance, and traffic regulations will have to be cleared out before implementing the autonomous vessels.

The completed gap analysis recognizes these same issues (see section 4). Most legal documents require a captain and a set number of crew to be on board before a vessel is allowed to depart. In autonomous vessels of the third degree no crew is on board and the captain is steering the vessels from a SCC. In case of an autonomy level of four, there is no captain, and the vessel is steering itself. It is not clear how this will impact liability and emergency cases as the vessel is legally not up to the current required standards. Another major issue is the traffic regulations, the identified problematic articles will require very complex technology to replace captain and crew and to eventually comply.

To research how autonomous vessels could deal with these extensive gaps, a few (Belgian) projects were discussed (see section 5). Smart Shipping uses the legal framework created in cooperation with the Flemish Waterway nv and complies with a strict test procedure. Seafar uses this same procedure but also mentions that some tests are happening with a full crew on board to comply with current rules and regulations. AUTOSHIP is comparable to Seafar and it is also trying to collect data to further improve gaps in legislation. These projects correspond with autonomous vessels of the third degree, no tests are currently being conducted with vessels of the fourth degree.

To complete the picture regarding autonomous shipping, other challenges were also briefly mentioned (see section 6). When further developing new projects, one should also take into account new safety challenges, issues regarding connectivity, infrastructure investments, social impact and additional costs of designing, building and maintaining an autonomous vessel.

In section 7, recommendations were made to further aid the development of a legal framework regarding autonomous vessels. Seeing as amending every applicable convention, law, decree etc. would be very time consuming, a separate legal framework is advised. This while keeping in mind the different levels of autonomy. There should also be a clear definition of what an 'autonomous ship' entails as current definitions of 'ships' are very broad. A third recommendation is a clear answer to the question what would happen is there is no crew or captain involved in the vessel operation. Questions regarding liability will eventually come up and need to be answered in advance. There is also a need for a better network up and around inland waterways to ensure a constant connection to the SCC and guarantee the same level of safety as a conventional vessel. Another worry is what an autonomous vessel can do to assist another vessel in need? There needs to be clarity whether simply alerting the authorities and emergency services is enough. A seventh recommendation is focussing on the increased digitalization by digitalizing the documents that need to be on board the vessel at all times. Lastly, the technical requirements of an inland navigation vessel need to be adjusted to vessels not complying with crew related infrastructure etc. and new standards should be created with a focus on new technology and advanced equipment.

Finally, a discussion (see section 8) described the difficulties regarding the research itself and makes some remarks regarding method, decisions made, used sources and conclusions.

It is clear that most issues lie with autonomous vessels of the third and fourth degree due to the fact that there is no captain nor crew on board. In case of the fourth degree there isn't even a captain involved. This makes for several legal challenges that will need to be addressed. We can conclude by saying that the current Flemish legal framework is a step in the right direction, but a lot of changes will have to be made if fully autonomous vessels will navigate through Belgian inland waterways in the near future.

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International

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The International Convention on Salvage, London, 28th April 1989
The International Regulations for Preventing Collisions at Sea, London, 20th October 1972

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Besluit van de Vlaamse regering van 21 mei 2021 tot wijziging van het besluit van de Vlaamse Regering 25 mei 2018 tot aanpassing van de regelgeving betreffende het vervoer van gevaarlijke goederen over de binnenwatern aan de wetenschappelijke en technische vooruitgang wat betreft de voorwaarden waaronder het vervoer van gevaarlijke goederen over de binnenwateren is toegestaan.
Decreet van 26 april 2019 betreffende diverse bepalingen over het mobiliteitsbeleid, de openbare werken en het vervoer, het verkeersveiligheidsbeleid en VVM - De Lijn,

Decreet van 6 juli 2012 betreffende het vervoer van gevaarlijke goederen over de binnenwateren

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Koninklijk Besluit van 24 september 2006 houdende vastelling van het algemeen politiereglement voor de scheepvart op de binnenwateren van het Koninkrijk

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11. Annexes

11.1. Smart shipping test procedure in Flanders – submitting application

Submitting an application

Before authorization can be given, the following documents must be submitted:

- A ConOps (Concept of Operations), in which at least the following is described:
  - What the purpose is of the pilot project;
  - On which waterways, waterway sections or parts of the port area the pilot project will be carried out;
  - The period for which the application is submitted;
  - Which safety and security measures are taken in the design of the ship for the implementation of the pilot project;
  - Which minimum risk conditions are identified in which the ship can operate safely and which fallback scenarios are implemented for when the ship cannot operate safely anymore.
  - General and technical information about the vessel and the level of autonomy;
  - An overview of which tasks will be performed by a human and which ones by a machine.
- A gap analysis of the Police Regulations and Crew Regulations:
  - An overview of the rules that cannot be complied with due to the nature of the innovation and the alternative way in which they nevertheless can be answered, guaranteeing an equivalent level of safety.
- A risk analysis, consisting of:
  - The identification and analysis of possible risks that could occur during the pilot project and the actions that could mitigate these risks.

Internal procedure

Based on the aforementioned documents, the evaluation committee will assess the safety and potential risks of the pilot project within 6 weeks. The committee consists of some fixed people who have a thorough technical knowledge and depending on the test request, it consists of people who have a good territorial knowledge of the trajectory that will be navigated during the tests. The Single Point of Contact for tests sends the test request out and then the committee has some time to get back with their comments and questions. After that the test applicant gets some time to answer the questions, process the remarks and adjust their application. Then this is sent back to the evaluation committee so they can give their consent or give additional comments if the response wasn't satisfactory. In some cases, there is also a live discussion with the committee members. This is usually what happens for new test applications. For small changes in a well-known test, written feedback is usually enough.

The committee assesses the safety and potential risks of the pilot project. They focus on navigation issues, crew requirements, technical requirements and risk analysis.

- The navigation issues are described in the ConOps and in the gap analysis of the Police Regulations.
- The possible deviations of the crewing requirements are discussed based on the ConOps, where the division of tasks between human and machine and information on the procedures in the Remote Control Center (RCC) are described. There is also a gap analysis document for the crew requirements.
- For the technical requirements, a gap analysis document is still in the making in cooperation with Seafar. In the meantime, the information is found in the ConOps in the chapters concerning design and safety measurements and in the risk analysis.

  Furthermore, the vessels which are equipped with devices for autonomous navigation are still in line with the ES-TRIN. Once chapter 12 would come into force, then we might have to consider a review. One of the main challenges is the RCC. We request applicants who use an RCC to be in line with chapter 7 as far as possible. Another challenge is to give an answer to safety issues where the crew is involved, eg doors in watertight bulkheads where an alarm is given. Someone has to respond to this alarm. Or any alarm from the engine or steering gear, or switching to the second independent drive unit within 5 seconds. The intention is to solve this last problem automatically depending on the alarm, because you can never rely on a wireless communication line.

  The inspection body (Commissie van Deskundigen) is involved in the CONOPS, but there hasn't been a full inspection of the devices and schemes of the vessels involved. Those additional devices are placed "out of the scope" of ES-TRIN and with the idea that we have to start gaining experience. Anyway, the equipment has no negative effects since the crew can still intervene a vessel according to ES-TRIN and there is always a possible "safe state" for the vessel (= vessel stops autonomous and sets light "unmaneuverable vessel"). We are waiting for chapter 12 because most of the equipment installed must meet chapter 12.
- The risk analysis covers all risks that are identified on the specific waterway.

When we defined the scope in which we would allow deviations of current rules and legislation, we decided to leave dangerous goods out of the scope. So for now applications regarding test projects involving dangerous goods get rejected. Another reason for rejection could be that the test trajectory is not suited for the test. This is for example the case if the applicant wants to test without crew on a busy waterway. Overall, the committee uses a case-by-case approach to accept or decline test applications.

If the application is subsequently approved, the applicant will be contacted for an interview in which all practical matters are discussed. After that, everything can be recorded in an experiment agreement. This agreement lays down the conditions under which the pilot project can continue. The tests are then carried out in accordance with the code of conduct (https://www.vlaamsewaterweg.be/sites/default/files/download/smart_shipping_code_of_conduct.docx) and the experiment agreement.

During testing, the testing organization completes a report on their pilot project, consisting of:

- A description of the testing activities, including date, position and time.
- A description of the problems encountered by the tester and how they were solved.

The frequency of this intermediate report depends on the project, but there definitely needs to be a report after every phase, before moving on to the next one. If a test consists of phases, the first one will always be to test the technology with people on board. So for example if the end goal is to test with an unmanned vessel, controlled from a shore control centre, the first phase will be to test the technology and the operations with somebody on board, who can still intervene if something goes wrong. Also, test applicants have to tell us whether they already did simulations or not. This is a question in the ConOps. Every time the applicant wants to move on to a next phase, the experiment agreement will be amended and sent to the evaluation committee for comments. There is a case by case judgement if the technology has proven to be ready to move on to a next phase and have fewer/no people on board of the vessel. The authorization can always be withdrawn in whole or in part if safety is endangered as a result or partly as a result of the pilot project.

What should be inside the intermediate report and in what form it should be submitted also depends on the specific case and the specific goals they have. With Seafar we evolved from evaluation after each phase to continuous evaluation: some people of the evaluation committee have full time access to the online logbook of the testing vessel and can start an evaluation at any given time. Of course we always expect an overview of how the tests developed, what problems they encountered and how they solved it plus the reasons why they think they are ready to move to a next stage. In the case of Seafar, there is the permanent evaluation possibility, but they always write us a request for amending the experiment agreement in which they explain the abovementioned topics and adjust their ConOps, gap analysis and risk analysis.

After the pilot project has ended, the full report will be signed and returned for validation within 2 weeks after the end.

11.2. Smart shipping test procedure in Flanders - code of conduct

1. Introduction

1.1. The present Code regulates the testing of automated vessels in a real world environment in Flanders.

In concrete terms, tests of this nature may take place on condition that the vessel is used in accordance with the applicable laws and regulations and providing a tester is present, or, in certain specific cases, minimally a test operator, who takes responsibility for the safe operation of the vessel.

1.2. It is up to the manufacturer or the testing organisation to ensure that innovative technologies for automated or fully automated vessels are developed and tested thoroughly before being brought onto the market. Much of this development can be done in test laboratories or on dedicated test tracks. However, to ensure that these technologies are capable of 'safe behaviour' in the various situations that may present themselves, they will need to be subjected to controlled testing in a 'real world environment' also. Thus, the testing of new automated vessel technologies on the inland waterways should be facilitated whilst care must be taken that these tests are designed and conducted in order to minimise potential risk.

1.3. This Code of Practice has been published to help manufacturers and/or testing organisations intending to test these technologies in real conditions. This Code of Practice provides clear guidelines and recommendations to maintain safety during this testing phase.

1.4.The present Code of Practice does not contain any actual rules of law but has been developed to promote responsible planning and carrying out of tests. Testing organisations shall use this Code in conjunction with detailed knowledge of the statutory, regulatory and technological framework

2. Object, scope and definitions

Object

2.1. This Code of Practice provides guidelines for organisations wishing to conduct testing of partially or even fully automated vessel technologies on the inland waterways in Flanders. The present Code lists the minimum conditions the competent authorities expect to be respected in order to guarantee safety and minimise potential risks. 'Minimum conditions' means that additional conditions may be imposed for specific applications which may vary according to the waterway and the kind of vessel covered by the application.

2.2. Naar verwachting dragen nauwkeurige tests bij tot een weldoordachte ontwikkeling van geautomatiseerde vaartuigen die, wanneer ze in 'automatische stand' worden gebruikt, blijk zullen geven van een voorbeeldig vaargedrag en op die manier de veiligheid van alle vaarvaarweggebruikers zullen verbeteren, alsook zorgen voor een vermindering van de uitstoot.
It is expected that careful testing will contribute to the well-planned development of automated vessels which, when operated in 'automated mode', will display exemplary sailling behaviour, improving the safety of all waterway users, and reduce emissions.

Scope

2.3. This Code of Practice is intended for the following applications:

- The testing of partially or even fully automated vessel technologies on the Flemish inland waterways (see 2.4).
- The testing of a wide range of vessels, from smaller automated scale models, through to more conventional vessels from all CEMT-classes.

Definitions

2.4. For the purpose of this documents, the following definitions shall apply

	Level	Designation	Vessel command (steering, propulsion, wheelhouse, …)	Monitoring of and responding to navigational environment	Fallback performance of dynamic navigation tasks	Remote control
Boatmaster performs part or all of the dynamic navigation tasks	0	No automation the full-time performance by the human boatmaster of all aspects of the dynamic navigation tasks, even when enhanced by warning or intervention systems *E.g. navigation with support of radar installation*				No
	1	Steering assistance the context-specific performance by a steering automation system using certain information about the navigational environment and with the expectation that the human boatmaster performs all remaining aspects of the dynamic navigation tasks *E.g. rate-of-turn regulator* *E.g. trackpilot (track-keeping system for inland vessels along pre-defined guiding lines)*				No
	2	Partial automation the context-specific performance by a navigation automation systems of both steering and propulsion using certain information about the navigational environment and with the expectation that the human boatmaster performs all remaining aspects of the dynamic navigation tasks				Subject to context specific execution, remote control is possible (vessel command, monitoring of and response to environment or fallback performance). It may have an influence on crew requirements (number or qualification)
System performs the entire dynamic navigation tasks (when engaged)	3	Conditional automation the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks, including collision avoidance[1], with the expectation that the human boatmaster will be receptive to requests to intervene and to system failures and will respond appropriately				
	4	High automation the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks and fallback operation, without expecting a human boatmaster responding to a request to intervene[2] *E.g. vessel operating on a canal section between two successive locks (environment well known), but the automation system is not able to manage alone the passage through the lock (requiring human intervention)*				
	5	Full automation the sustained and unconditional performance by a navigation automation system of all dynamic navigation tasks and fallback operation, without expecting a human boatmaster will respond to a request to intervene				

1 "Collision avoidance" is the critical task in responding to the environmental conditions (other vessels, bridges,…).
2 This level introduces two different functionalities: the ability of “normal” operation without expecting human intervention and the exhaustive fallback. Two sub-levels could be envisaged.

Testing organisation

2.7. A testing organisation is any institution or person wishing to test (new) technologies for partially
or even fully automated vessels on the inland waterways in Flanders. The testing organisation submits the application and bears full responsibility for the tests to be conducted.
Tester

2.8. A tester is the person who is seated in the vessel in a position where he is able to control the vessel’s speed and direction at any time.
Test operator

2.9. A test operator is the person who oversees testing of an automated vessel. The test operator must not necessarily be seated in the vessel but must at all times be able to override the automated operation of the vessel, especially when there is no tester in the vessel.
Test assistent

2.10. A test assistant assists the tester or test operator with the testing, for example by monitoring the information relayed via screens or other information systems designed to provide feedback and by observing the reactions of other inland waterway users.

3. General requirements

Safety requirements

3.1. Het is de verantwoordelijkheid van de testorganisatie om zich ervan te vergewissen dat alle geplande tests voldoen aan de toepasselijke wetgeving en dat de betrokken vaartuigen
geschikt zijn om aan het scheepvaartverkeer deel te nemen, voldoen aan alle toepasselijke vaartuigvereisten en kunnen worden gebruikt op een wijze die verenigbaar is met de van kracht zijnde regelgeving.
Responsibility rests with the testing organisation for ensuring that all tests planned meet the relevant

legislation and that the vessels involved are worthy to take part in the inland waterway traffic, meet all the relevant vessel requirements and can be used in a way that is compatible with the legislation prevailing.

Testing organisations shall:

- ensure that testers and test operators hold the relevant certificates and have received the appropriate training (see Section 4);
- conduct a (prior) risk analysis of any tests proposed and develop appropriate risk management strategies (with documentation in support);
- be aware of the possible impact of these tests on other inland waterway users;
- allow representatives of the competent authorities to attend the tests.

Where tests on the inland waterways are considered, an application form will have to be completed.

3.2. The responsibility for the safe and orderly testing of the technologies in question on the inland waterways invariably rests always with the testing organisations. The mere compliance with the present guidelines does not by definition mean that all reasonable steps to minimise risks have been taken.

3.3. Where the vessel also carries passengers, the testing organisation (or tester) is obliged to inform them about the tests.

Insurance

3.4. All statutory requirements in matters of insurance apply. Anyone conducting tests with automated vessels on inland waterways must be covered by appropriate insurance and also satisfy the other statutory requirements (a copy will need to be submitted).

Competent authorities

3.5. Testing organisations must engage with the competent authorities with responsibility or competence for the test location (the waterway manager).

3.6. Any specific infrastructure requirements that are considered necessary within the framework of the tests, including traffic signals, will need to be put in place as agreed with the inland waterway manager.

3.7. Testing organisations shall compile a report after each test on the inland waterways. Where necessary, they shall propose any changes that may be required for risk management purposes. This report shall be discussed with the relevant authority (the waterway manager).

Engagement

3.8. Communication-related initiatives shall be coordinated with the competent authority (the waterway manager).

3.9. Once the necessary permits have been obtained and no less than 3 working days prior to the start of the trials, the testing organisation shall notify the times and locations of the test and of the registration data of the test vessels via the following address: smartshipping@vlaamsewaterweg.be

4. Requirements for testers, test operators and test assistants`

Requirements for a tester/operator overseeing the tests

4.1. The testing of automated vessels on the inland waterways shall be done in the presence of a suitably trained tester or a test operator. Details with regard to the required boatmasters' certificate and training are set out in sections 4.5 to 4.9.

4.2. The tester or test operator is responsible for the safe operation of the vehicle at all times. The tester and test operator must be familiar with and understand the systems under test, including their capabilities and limitations, and must be able to anticipate the need to intervene and resume control when necessary.

4.3. The tester or operator must have been duly authorised by the testing organisation to fulfil the role in question. Testing organisations shall have robust risk management, process and training procedures in place for testers and test operators, and shall ensure that the aforesaid persons hold the appropriate boatmasters' certificate.

4.4. Those entrusted with testing are expected to have knowledge of the law and regulations applicable. Law and regulations can be found at https://www.visuris.be/Reglementering

Certificate requirements

4.5. The tester or test operator must hold the appropriate category of certificate for the vessel under test. This applies even if the vessel's ability to operate entirely in automated mode is being tested. It is strongly recommended that the certificate holder also has several years' experience of navigating the relevant category of vessel.

4.6. The testing organisation shall take due care in its selection and guidance of testers and test operators. Testing organisations are expressly advised not to use persons whose navigation history indicates that they may increase the possible risks.

Tester or test operator training

4.7. Testing organisations shall develop and implement procedures to ensure the competency of testers and test operators. Testers and test operators need skills over and above those of skippers of conventional vessels, and/or in normal conditions. For example, it is important to ensure that they have an excellent understanding of the capabilities and potential limitations of the technologies under test and are able to assess and, where possible, control the risks associated therewith. It is also recommended that they get the opportunity to familiarise themselves with the characteristics of the vessel and technologies under test.

4.8. Testers and test operators must be familiar with the modalities of the automated systems under test, and be aware of the situations in which they may have to intervene. Training should cover potentially hazardous situations that may be encountered, and the appropriate action to be taken at that moment in time - including safely resuming control.

4.9. It is vital that those conducting the tests are fully aware of the mode in which the vehicle is operating and of the manner in which control is passed between the tester or test operator and the vehicle.

Tester and operator working hours

4.10. Testers and operators shall remain alert and ready to intervene if necessary throughout the test period.

Tester/operator behaviour

4.11. Testing organisations shall implement clear rules regarding tester and test operator behaviour and ensure that these are known and understood.

4.12. Testers and test operators should be conscious of the way they are perceived by other road users, for example continuing to maintain gaze in directions appropriate for normal navigation.

Test assistents

4.13. Depending on the nature of the tests being conducted and the vehicle involved, testing organisations may deploy a test assistant. For instance, if the vessel is a conventional one which has been adapted to include functions related to automated technologies, a test assistant can assist the tester by monitoring information displayed on screens or via other feedback systems.

5. Vessel requirements

General vessel requirements

5.1. Any organisation wishing to test automated vessel technologies on the inland waterways must ensure that the vessels under test can be used in a way that is compatible with the legislation prevailing in Belgium.

Experience with technologies under test

5.2. Organisations wishing to test automated vessel technologies on the inland waterways shall demonstrate that the vessels and/or technologies have been adequately tested beforehand.

5.3.Vessel sensor and control systems should be sufficiently developed to be capable of appropriately
responding to all types of inland watereay users which may be encountered during the test in question.

Data recording

5.4. Automated vessels under test should be fitted with a data recording device that is capable of recording data from the sensor and control systems linked to the automated functionalities, including
other information associated with the vessel's movements.

5.5 As a minimum, this device should record the following information:

- whether the vessel is operating in classic or automated mode;
- the speed of the vessel;
- steering commands and activation;
- braking commands and activation;
- activation of the vessel's audible warning system;
- the location of the vessel (on the waterway);
- the operation of the vessel's lights and indicators;
- sensor data concerning the presence of other waterway users or objects in the vicinity of the vessel;
- remote commands that (may) influence the vessels's movements (where applicable);

Where some of the aforesaid elements are irrelevant within the framework of the proposed tests, or cannot be recorded, the testing organisation shall explain this on the application form.

5.6. These data should allow one to establish who or what was controlling the vessel at the time of an
incident. The data shall be securely stored and, in the event of an incident, be provided to the official
bodies upon request. Testing organisations are expected to fully cooperate with the competent authorities in the event of an investigation into an incident.

5.7. In addition, it may be useful to fit vessels under test with a video and audio recording system.

However, this device should not be considered as an alternative to the data recording requirements specified in the section above.

Data protection

5.8. Testing is likely to involve the collection and/or processing of personal data. Where data are collected about the behaviour or location of individuals in the vehicle allowing those individuals to be
identified, the activity comes within the scope of the General Data Protection Regulation of 25 May 2018. The testing organisation, and by extension all the persons involved, shall ensure that the data protection legislation is complied with, including the requirement that the personal data are used fairly and lawfully, kept securely and for no longer than necessary.

5.9. A (prior) assessment of the impact on privacy of the proposed tests and/or the procedures implemented is not a legal requirement but can be useful in terms of helping a project comply with the data protection legislation. An assessment like this can be developed flexibly and proportionally,
depending on the complexity of the test.

Cyber security

5.10. As stated in section 4, a tester or test operator shall oversee the movements of the vessel under test at all times so that control of the vessel can be safely resumed whenever necessary.

5.11. Nevertheless, manufacturers providing vessels, and other organisations supplying parts for the tests, need to ensure that all prototypes of automated controllers have appropriate levels of security built into them to ward off any risk of unauthorised access.
5.12. Testing organisations and/or other entities involved are advised to adhere to and apply the security principles as set out in Standard IEC 61508, or equivalent on software trustworthiness, as best as possible.

Process for transition between automated and classic modes

5.13. Een belangrijk onderdeel van de veiligheid van het testen van geautomatiseerde vaartuigen is het beheer van de overgang van klassieke besturing naar automatische stand en, in het bijzonder, van de automatische stand terug naar klassieke besturing.
An important part of the safety of automated vessel testing is the management of the transitions from classic control to automated mode and, in particular, from automated mode back to classic control.

5.14. The system used shall:

- be straightforward and easily understood by the tester or test operator;
- ensure that the tester or test operator can establish clearly whether the vessel is in classic or automated mode;
- ensure that the tester or test operator is given appropriate and ample warning to resume control of the vessel whenever necessary;
- allow the tester or test operator to quickly and easily resume control of the vessel whenever necessary.

5.15. Ensuring minimal transition periods between classic and automated modes, with the least possible risk, forms an important part of the vessel development process and the organisation of the envisaged tests.

Failure warning

5.16. Prior to the start of any test, the tester or test operator shall check the proper functioning of the system under test, including the proper functioning of the emergency procedures put in place.

5.17. In the event of a malfunction or failure of the automated navigation systems under test, the tester or test operator must be notified by means of an audible signal which may be accompanied by a visual warning. The emergency procedure(s) put in place are activated and, if necessary, the test must be aborted. Testing shall not be resumed until such time as the system is demonstrably operational again.

5.18. The vessel's automated braking and steering systems shall be designed in such a way that, in the event of failure, manual braking and steering remains possible.

Software versions

5.19. Automated driving systems will require the interaction and the correct functioning of several computers and/or electronic control modules. It is essential that:

- all software versions and revisions used during testing are documented and recorded;
- all software versions and revisions have been extensively and demonstrably tested (reporting)
  before being deployed on the inland waterways.