MIIP 2021-007: NAVIS

Nederlandse Autonome Veerponten: Innovatie Stappenplan

Authors:
Boogmans, B. (TU Delft, Researchlab Autonomous Shipping)
Karaarslan. S. (Stichting Projecten Binnenvaart)
Scholtens, M (NMT)
Uithof, K. (NMT)

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NETHERLANDS MARITIME TECHNOLOGY

Netherlands Maritime Technology BV
Willemswerf • Boompjes 40 • P.O. Box 23541 • 3001 KM Rotterdam
T +31 (0)10 44 44 333 • **F** +31 (0)10 21 30 700 • **E** info@maritimetechnology.nl
IBAN: NL95ABNA0458743666 • VAT no.: NL816153905B01

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1. Introduction

About MIIP

Every year, the Maritime Innovation Impulse Projects (MIIP) are organized by the *Nederland Maritiem Land (NML)* Innovation Council, in collaboration with the Dutch Ministry of Economic Affairs and Climate Policy. These projects aim to give maritime innovations a financial impulse. This can be used to perform feasibility studies or take the first steps towards project development.

Participating projects need to align with one of the four objectives of the Maritime Innovation Contract: Winning at Sea, Clean Ships, Smart & Safe Shipping, or Effective Infrastructure. The projects are assessed on the basis of the intended contribution to the realisation of these objectives. The future perspectives, possible follow-up projects combined with the quality and breadth of the partnership are also taken into account, regardless of whether they are affiliated with the NML Innovation Council.

Goal of NAVIS

This project outlines a roadmap for incremental innovation towards autonomous ferries. The electrification of ferries provides the necessary platform for automated or autonomous systems, while the autonomy itself contributes to increased safety and efficiency. When applied at large scale, the economic benefits could be significant. More zero emission ferries can be put into operation in a cost-efficient way, and that way contribute to objectives of improved mobility and emission reduction, as formulated in the Green Deal for sea shipping, inland shipping, and ports.

The roadmap will have to provide for a step-by-step introduction of automated functionalities, in order to keep developments manageable and affordable for the often small organisations that run these ferries. A gradual introduction of automated or autonomous functions will also provide the opportunity to test sub-functionalities while appropriate regulations and functionalities are still in development. The roadmap can serve as an inspiration for pilot projects for various companies and knowledge institutions.

The focus of this research lies primarily with the electric/hybrid ferries on Dutch inland waterways.

Project Partners

The project is being carried out by Netherlands Maritime Technology Foundation, Stichting Projecten Binnenvaart and the Technical University Delft (Researchlab Autonomous Shipping), supported by Holland Shipyards, Damen Shipyards, Captain AI, Marinminds, Metropoolregio Rotterdam Haaglanden, Landelijk Veren Platform, Provincie Zeeland, Rotterdam Maritime Services Community, and Nederlands Forum Smart Shipping (SMASH!).[1]

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[1] Contact persons within each organisation and their contact details are available through project leader Kasper Uithof (uithof@maritimetechnology.nl).

2. Definitions and Terminology

The goal of this section is to clarify to clarify baseline definitions and their distinctions. Some terms have different interpretations depending on the person asked, while for others a commonly accepted meaning exists. Various interpretations of terminology that describe novel ship developments will be discussed. This section ends with recommendations towards overcoming misinterpretation.

Having a mutual understanding of a concept, such as ‘autonomous’, ‘smart’ or ‘green-ship’ could have the following effects:

- Shared interpretation increases effectiveness of discussion
- Regulations are easier formed
- Novelty becomes more distinguished
- Expectations align

Common terminology is discussed in four groups.

- Automation & Cybernetics
- Autonomy
- Unmanned, crewless & remote-controlled
- Zero emission & electrically powered

Automation, Cybernetics

The International Maritime Organisation discussed new terminology for high-tech vessels. Automation had definitions proposed as follows (International Maritime Organisation, or IMO 2021):

Automatic Pertaining to a process or equipment that, under specified conditions, can function without human control.

Automation The implementation of processes by automatic means

The core of this concept is about transfer of a task from a human to a machine. What tasks are transferred, and to what extent depends on the context of the problem. For an automated vessel, one could ask the question what tasks are now done by a machine. There is generally a shared idea on what tasks are done by the vessel, often focussing on motion control tasks. These terms seem to generally have a consistent interpretation.

Automation can be realized with many approaches, one of which is the use of feedback-control systems, bringing us to the field of cybernetics. (Smithers T. 1997)

Self-regulating, or Cybernetic systems are self-regulating, not just able to move or to act by themselves but are also able to regulate and control their movements or actions so as to maintain their effectiveness in the face of disturbances and perturbations, according to some predefined control law or rule of regulation. Automation can be (but is not necessarily) reached through making vessel controls self-regulating.

Autonomy

Autonomy of ships is a term used in a variety of ways. Common interpretations are (but are not limited to):

Definition 1: Automated to a great extent

In the context of ships, autonomy means that one or more of a ship system's processes or equipment, under certain conditions, is designed and verified to be controlled by automation, without human assistance (Proposal, IMO 2021).

Definition 2: Self-regulating

Autonomy, as related to robots, we define as: The extent to which a robot can sense the environment, plan based on that environment, and act upon that environment, with the intent of reaching some goal (either given to or created by the robot) without external control. (Beer et al. 2014)

For vessels this could mean that the system has a feedback control loop, capable of sensing the state of the vessel (e.g. position, heading, velocities) which is subsequently used to decide the appropriate action to take (e.g. thruster speeds, rudder angles) according to a designed control law.

Definition 3: Self-Law making

A system is an autonomous system when it regulates its behaviour according to rules or laws that it has constructed for itself (Smithers T. 1997)

Smithers points out that the ability of adjusting your own behaviour should make autonomy distinct from automated and self-regulating systems. Meaning of autonomy as 'self-governing' or 'self-law-making' is more in line with the original meaning where it referred to a person or state, similar to use in other sciences such as biology, sociology, philosophy and law. This third definition also distincts self-regulation from self-governing as two valuable independent concepts.

Example: Is a simple cable ferry autonomous?

Ambiguity will be illustrated through an example. Consider a cable ferry, able to move in one direction over a small canal using electric winches and cables. A passenger can express desire to cross by pressing a button, upon which the ferry pulls itself to the other side and stops upon touching the shore. The considered section of water is inaccessible for other traffic.

Is this simple cable ferry autonomous? The problem to solve in this scenario (transfer of a passenger) is simplified by having a limited set of tasks (only movement, no environmental awareness), a simple environment (no traffic) and only one degree of freedom (in the direction of the cables).

According to the first definition "Automated to a great extent" this system can be considered autonomous, as all the functions are taken over by a machine. The term autonomous does not relate to the complexity of the solution.

The second definition "self-regulating" can also specify this cable ferry as autonomous, as the self-regulating behaviour can be observed in the ability of the ferry to detect the opposite shore and stop upon reaching it.

The third definition "self-law making" does not specify this ferry as autonomous, as the simple control system has zero means to change its own approach to solve the problem of transporting a passenger.

This example illustrates how a ferry can be classified as autonomous or not differently, depending on the used definition. Since 2019, the Maritime Safety Committee (MSC) of the IMO had discussion on definitions of autonomy in the shipping context, but has thus far not settled any in its yearly meetings. It is worth realizing that various definitions of autonomy are in regular use, even beyond the three presented ones. Misinterpretation can be avoided by opening discussions on the interpretation by involved parties, or by simply using other terms.

Unmanned, Crewless, Remote controlled

A vessel is controlled by some entity; a human, machine or a combination of both. Various technologies exist that have the potential to realize communication over different distances while maintaining required bandwidth and network reliability. This allows a controller to not be on board of the vessel anymore, yielding a remote-control scenario.

Remote-controlled *decisions on controlling vessel are made from another vehicle or station.*

This does not specify the nature of the controller. Moving the decision maker away from a vessel can be done for different reasons for human and machine controllers. For instance, more computational power can be available on shore, making more complex decision-making algorithms feasible, provided that the network is reliable and has acceptable latency.

Unmanned: *No humans are on board of the vessel.*

This term does not specify how the ship is controlled. It could be controlled by a machine or a human via remote-control.

Crewless: *No humans are on board of the vessel that have responsibilities in ship operation.*

Passengers can still be present.

Zero Emission, Electrically Powered

Energy to power vessel systems can originate from various sources such as (fossil) fuels or electrically stored as in batteries. Switching power source from fossil fuels to battery powered electrical engines is a common approach to develop towards climate goals such as reduction of carbon-dioxide emission. An energy source is required regardless whether a vessel is controlled by a human or a machine.

Vessel automation can theoretically contribute to achieving climate goals by improving efficiency, but it does not necessarily do so.

Although automated control systems often rely on electric power as a main source, vessel control automation can also be applied using others, such as common combustion engines. Functions of power-source and ship-control often affect each other, but are fundamentally distinct problems that require a solution.

Terminology Used in this Report

Although the debate on terminology is far from concluded, for the purpose of this report, we will adhere to the abovementioned definition 1 of autonomy, being automated to a great extent. This seems the most appropriate to the applications we are aiming at. As a consequence, the terms autonomous and automated are both used to some extent in this report, where autonomous is mostly applied to the whole ship or system. The ship achieves a higher level of autonomy using increasingly automated systems and sub-systems.

3. CATEGORIZING VESSEL AUTOMATION

This section aims to give recommendations on categorizing automated systems. First, ferry functions are discussed from multiple levels, followed up by a comparison of a selection of categorizations that describe the degree of automation.

FERRY (SUB-)FUNCTIONS

The main goal of a ferry is to transport people[2] across a waterway, often affected by criteria such as speed, passenger & environmental safety, comfort, financial feasibility, reliability and capacity. How these criteria are valued depends on the use case.

A ferry has many tasks that need to be achieved for successful operation, ranging from motion control, monitoring of passengers/cargo, docking, undocking, fuelling, maintenance and more. Each task can be automated independently to realise less human involvement in a particular task. If 'vessel automation' is discussed, it needs to be clear what tasks are referred to and which aren't. Table 1 shows a selection of tasks that are required for a ferry to operate. Most functions can be further split into subfunctions that again can have different degrees of automation.

Function	Examples of subtasks
Motion control	• Sensing • Estimating current scenario • Decision making • Create forces acting on the vessel
Power management	• Monitoring power • Fuelling or charging
Respond to exceptional situations	• Collision protocols • Monitoring passenger wellbeing
Maintenance	• System health Monitoring • Repairs
Interaction with passengers	• Ticketing • Behaviour management

Table 1 Examples of subtasks of vessel functions

Vessel motion control automation commonly plays the central role within vessel-automation, where other tasks are more optional, depending on one's goal and viewpoint.

Vessel motion control is often realized with implementation of a feedback loop. Sensor data is used to formulate a state estimate such as position and heading, but optionally also velocities, traffic, environment and more. This estimate is used by the controller to decide actions that the vessel will take to achieve its goal. This is often done by distinction of guidance (trajectory planning) and motion control (realizing planned motion) tasks.

One can subdivide the overall task of vessel motion control into four subsystems, as shown in Table 2.

[2] on foot, by bicycle or in vehicles depending on the ferry type

Subfunction	Human operated	Examples of automation
Sensing Acquire information	Various senses, such as eyesight, hearing and feeling of accelerations	*The vessel itself:* • Position: GNSS • Orientation: Compass • Actuators: rudder angle with rotary encoder, power consumption *Environment:* • Electromagnetics: camera, Radar, Lidar • Below surface: Sonar • Communication: AIS, VHF
State estimation Conceptualizing information	The human brain filters, analyses and conceptualizes information to formulate an idea of the current situation.	• Data from multiple sources is combined to formulate an accurate state (sensor fusion). • Position determined by processing a camera stream using surrounding objects as a reference • Radar signal is processed to recognise vessels/objects among noisy data
Decision making Choosing action	The skipper plans a route and decides how to respond	• Heading control • Dynamical positioning • Trajectory tracking
Actuation Apply forces to the vessel	Manually pushing, towing, or rowing	• Propellers • Fins • Rudders

Table 2 Vessel motion subfunctions

This is just one approach to subdivide the task of vessel motion control. It should be noticed that each subtask can realized by a human or machine or a combination of both. It is already common in industry to have subfunctions of ship control fully or partially automated.

- A skipper might use his own senses, supplemented with information from automated sources such as radar. In some scenarios, as for example operation of commercial vessels in dense fog, full reliance on automated sensing systems such as GPS and radar is possible.
- Sensed information is already being processed by computers to aid state estimation. An example of this is a radar system that not only displays data, but also recognises patterns to detect objects. This information is subsequently displayed to a skipper to aid decision making.
- Heading control systems, often called autopilot, have automated steering of large vessels on open sea since the 1930's to lighten the burden on operators and reduce fuel consumption. More recently similar systems (e.g. trackpilot) are also applied on inland vessels. Although early autopilots could maintain a set heading, nowadays they have developed into multi-layered control systems with increased functionality, following variable waypoints. Dynamic positioning systems are commercially applied to control vessel motion during e.g. heavy lifting. Application of forces is commonly automated using engine powered propellers and rudders.

Categorizing Degrees of Vessel Automation

It is useful to split up the extent to which vessels can be automated in different categories. Numerous categorizations exist for automation of a system, where a couple do this specifically for ships. Table 3 shows various benefits and disadvantages when using such levels.

Benefit	Disadvantage or risk
• Accelerate conversation • Make content understandable • Make policies fitting to an implementation	• Over simplification creates false expectations and assumptions • Overly detailed categorizations are unattractive to understand for a broad audience

Table 3 Pros and cons of using a multidimensional approach for vessel automation

Categorizations differ in the way that levels of autonomy or automation are set, tailored to meet goals for the categorization. For instance, in the Smartport-whitepaper[3] three stages of autonomy (beyond manual operation) are considered ranging from one (increased sensors & decision support) to three (fully autonomous). IMAREST[4] expresses the relation between operator and machine in five ''human and machine interface status'' levels, additionally specifying for each level if operators are located on the vessel or not.

Many more categorizations and taxonomies of autonomy or automation exist, such as shown in Parasutran et al. (2000), in which indexes are shown and compared with different ways of categorizing ranging from a few levels, up to others that specify more than ten. Which one to use strongly depends on the purpose or goal of the categorization.

If a categorization indicates the automation level of a ship as a whole, we need to be able to determine in what category a vessel falls. This is however complicated by the fact that the overall ship system consists of many subsystems that can each rely on human intervention to varying degrees. Expressing automation on a single linear scale thus complicates determination in which level a system falls. One vessel may for instance have its sensory tasks fully automated (e.g. with cameras and GPS) while decisions are fully made by a human. Another vessel system may have sensing and decision-making automated, where there is still active reliance on a human to intervene if need be.

A one dimensional scale expressing automation of multiple subtasks can create assumptions on the order that automated developments will take place. Consider an example of a categorization that determines degree of automation of a certain ship on a single axis, shown in Figure 1.

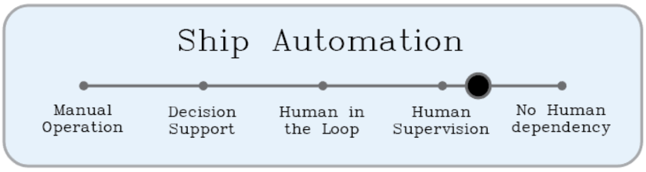

Figure 1 Single degree of ship automation.

This example categorization leaves ambiguity for determining a vessel's degree of automation, raising questions like: "*What part of the vessel is exactly automated?"* and *"To what extent are the functions automated?"* Alternatively, each subfunction can have its reliance on humans expressed individually, as illustrated in Figure 2.

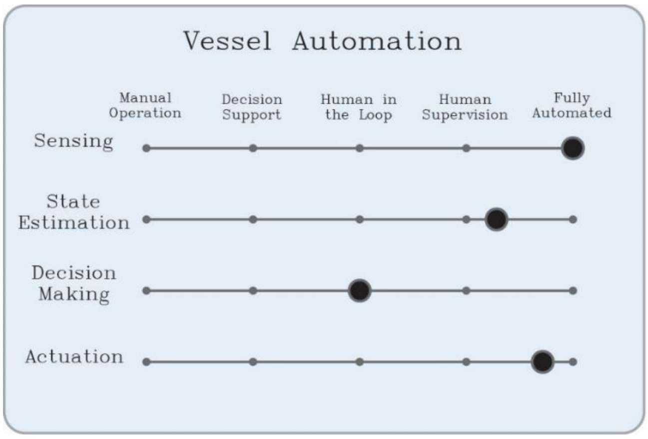

Figure 2 Multiple degrees of ship automation

[3] https://smartport.nl/wp-content/uploads/2019/04/SmartPort-whitepaper-SmartShipping.pdf
[4] https://www.imarest.org/reports/1055-autonomous-shipping-putting-the-human-back-in-the-headlines-ii/file

Both categorizations show slider-bars indicating a degree of automation of the same ship system as a use case. The first categorization can face challenges to properly define its levels such to apply on use cases objectively. The second categorization aims to solve this through subdividing the overall ship task in subtasks with each their own degree of automation. The second categorization better indicates the state of automation efforts for this vessel, illustrating where this solution is advanced, and on what facets it isn't.

The two examples shown here aim to illustrate how expressing degree of ship automation per subfunction can be advantageous over ones that express total ship automation level over one axis. Categorizations can be split into more levels, with the risk of making it complex.

There are many ways to make categorizations which can work as a useful tool. In the end, there is a trade-off between accurately and transparently representing a system versus keeping it easily understandable. This chapter points out that it is key to define which functions of a vessel are automated and to what extent, before we can form meaningful categorizations.

It is suggested to consider all relevant (sub)functions of a ferry, for the different ferry types, and express the automation for each component or subsystem to have a good representation of the actual degree of automation of the overall vessel system. This approach will also contribute to the approach for an incremental innovation and step-by-step introduction of automated/autonomous functionalities towards autonomous ferries.

4. An Overview of the Dutch Ferry Market

The Dutch ferries service sector consists of approximately 313 ferry services and about the same number of vessels (Hoekstra, 2017) (Kusee, december 2018). The foundation "Vrienden van de Voetveren" provides a visual overview of all the ferry services in the Netherlands[5]. These ferries bring people, bicycles and vehicles to the other side of the water every day. On an annual basis more than 50mln persons are being moved. They are therefore an important link between the shore and the water for commuters, schoolchildren and recreational users. The scope consists of ferries with a connection over water that is publicly accessible, located on a through route with at least two stops, and offering a more or less regular service. Hence, cruise vessels and tour boats on the inland waterways and/or at sea are not taken into account.

Category	Type of transfer	Nr of ferry services
utilitarian function	car ferry	53
	bicycle-pedestrian ferry	41
recreational function	car ferry	2
	bicycle-pedestrian ferry	99
	foot ferry	12
salt water ferries	car ferry	5
	express services	4
	watertaxi	1
self-service ferries	bicycle-pedestrian ferry	32
	foot ferry	56
international	car ferry	5
	bicycle-pedestrian ferry	1
watertaxi's	foot ferry	2

Table 4 Number of ferry services per category and type of transfer, from Hoekstra (2017)

In addition to its social importance, the sector also plays an economic role. The utilitarian, recreational and seaborne ('salt') ferry services had an annual total annual turnover from ticket sales of approximately €99.1mln in 2015, consisting of €33.5mln for the utilitarian ferry services, €4mln for the recreational ferry services and €61.6 for the salt ferry services (Hoekstra, 2017).[6] The economic and social value of the sector is significantly higher. The three segments create in total approximately 1.000 FTE and in addition 842 volunteers for the recreational ferries. The social value amounts to approximately €484 million for the utilitarian and recreational ferry services.[7] This is mainly explained by detour kilometres saved annually and the employment created by all the ferries in the Netherlands. (Groenendijk, de Kleuver, Ubbens, & van der Geest, 2020).

Since the ferry sector is quite diverse, a thorough categorisation must be made so that the main technical, organisational and regulatory challenges can be identified for the various groups within the overall sector. The categorisation is made based on the following relevant aspects:

- Type of transfer
- Ferry model
- Sailing period and sailing times
- The function performed

[5] https://veerponten.nl/
[6] No turnover figures are available for self-service ferry services and water taxi services; these are not included in the overview.
[7] The economic and social value of the salt ferry services is also very substantial, but no figures are available for this segment.

- Sailing environment and conditions

By Transfer Type

If a classification is made based on the type of transfer, then three different types can be distinguished:

- A car ferry being able to transfer cars, bicycles and pedestrians
- A bicycle-pedestrian ferry transfers both bicycles and pedestrians
- A foot ferry transferring pedestrians only

By Ferry Model

As regards the ferry models first of all a distinction can be made between ferries that can manoeuvre freely over the water surface (3 degrees of freedom) and those with constrained motion (1 degree of freedom).

Ferries		
Fast ferries(30-60 km/h)	Slow ferries(6-12 km/h)	
	Non-free sailing	Free-sailing
hydrofoil catamaran swath craft hovercraft	cable ferry manual operation self-service cable ferry self-service chain ferry self-service ferry electric cable ferry with motor yaw ferry yaw ferry with engine cable ferry electrically powered ferry wagon floating ferry	motor ferryboat motor ferry motor ferry head loader motor ferry side loader motor ferry without valves rowing boat rowing boat with outboard engine solar-powered ferry electric ferryboat sailing boat

Table 5 Overview of ferry types, from Hoekstra (2017)

Ferries that cannot manoeuvre freely can roughly be divided into three sub-models: *cable ferries*, *chain ferries* and the so-called 'gierponten' or *yaw ferries* which makes use of the current. All these three models have a limited ability to manoeuvre as they use a cable or chain for guidance on the water.

The models having a cable are common in the Netherlands. A cable has been laid between the two banks. This is normally at the bottom of the water, so that shipping is not hindered by this cable. When the ferry crosses, power is used to tension the cable. The required power is generated by an on-board diesel engine, a shore engine/shore electricity or simply by hand power. The ferry then pulls itself to the other bank. During the crossing, other shipping traffic has to wait because the cable is above water or just below the surface of the water.

There are also high cable ferries with an overhead cable or very small ferries to which a circular cable is attached running over a pulley on both banks. You can propel yourself (or the ferry if it is on the other bank) by pulling the cable manually.

Ferries using a chain have a drive mechanism with a turning wheel on both banks and on the ferry itself. Turning the wheel manually ensures that the ferry is propelled, there are also types using electrical power instead of manual power. The chain runs under water from one bank to the other.

A yaw ferry is a ferry where the driving force is provided by the current. A yaw ferry makes use of this current. In order not to drift away, a yaw ferry must be anchored. This can be an anchor placed on the bottom in the middle of the river. Attached to the anchor is a long cable that is attached to the ferry on the other side. In order for the cable to be visible to shipping traffic, a number of small yaw boats are attached. In a canal where there is no current, operating a yaw ferry would not be possible. Figure 3 provides an overview of the working method of a yaw ferry.

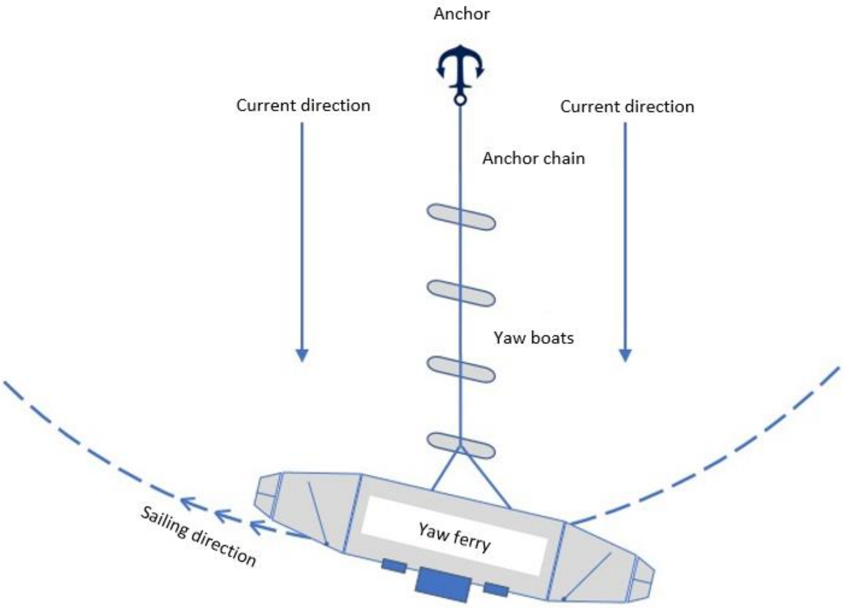

Figure 3 Working method of a yaw ferry[8]

Ferries that can manoeuvre freely can be distinguished in two ways, based on sailing direction and speed. In most cases, these ferries cross the water at right angles. However, there are also ferry services that sail in the lengthwise direction of the water. The ferries that travel lengthwise are, in general, able to reach a higher speed of 30 to 70 km/h. For ordinary ferries, the maximum speed is limited to 25 km/h.

For ferries that cannot manoeuvre freely, it can be said that the complexity of the sailing route is relatively low. This certainly applies to the small ferries (bicycle-pedestrian and foot ferries) without a captain on board. This will also create an opportunity for making the vessel autonomous, which makes it an interesting use case for early commercialisation.

By Sailing Period and Sailing Times

The sailing periods differ considerably across the provided ferry services, in general there are services operating all year around and other services provided only during a part of the year depending on market conditions. Ferry services that are provided during a limited period of the year are usually from the end of March to October. These are often services targeting the leisure market. Ferry services operating all year on usually do not target a specific group. These include people on the way to work or school, especially during peak hours of working days, but also recreational users may use these services.

Also the sailing times of the ferry services differ considerably, depending on the provided type of service and market conditions. Ferry services in the leisure market start usually later in the day than ferries services not targeting a specific target group such as the 'Waterbus' in Rotterdam.

By Function Performed

In terms of the performed function, every ferry service has one primary function, which is to transport

[8] https://veerpontculemborg.nl/geschiedenis/

a person from point A to point B. The users of the ferry service may have different motives though. As already shortly touched upon in the previous chapter, the motives can be divided into four categories:

- Commuter traffic
- Business traffic
- School traffic
- Recreational/tourist traffic

Ferry services targeting the first three categories are mainly performing a utilitarian function, whereas services targeting the last category are mainly performing a recreational function.

By Type of Waterway and Corresponding Sailing Conditions

Given the Dutch ferry market, a distinction is often made between fresh and salt waters and the corresponding differences in sailing conditions. Rivers, canals and lakes mainly consist of meltwater and rainwater, or so-called fresh water. Whereas, the Wadden Sea[9] and the Western Scheldt deal with seawater. The difference in sailing conditions associated with the difference in water (freshwater/saltwater) has an impact on the required automated functionalities. For example, on salt waterways you generally have to deal with rougher water, a wider crossing and greater distance from shore (shore control) which can make digital connection to shore more difficult as well as physical human intervention in case something goes wrong. A similar distinction can also be made within the fresh waterways category itself. The required automated functionalities will be different for ferries that can manoeuvre freely and navigate in the lengthwise direction of the water, such as the Waterbus services that have several stops, compared to small cable ferries that cannot manoeuvre freely.

By Navigation- and Vessel-Specific Technical Rules & Regulations

In addition to the basic stock taking in the previous section, this section will dive into the relevant nautical and vessel-specific technical requirements to assess which rules apply at the moment and whether different rules apply to the given type of ferries.

The navigational rules on waterways in the Netherlands depend on the waterway a vessel is sailing on. However, in general and for simplicity the ‘Binnenvaart politie reglement’ (BPR) can be taken as a starting point. The BPR contains the traffic regulations for the Dutch inland waterways. For example, it specifies the signs and other traffic symbols, the lighting, and sound signals to be used by vessels, and the rules for taking the right of way and evasive action on the water[10].

The BPR applies to all vessels, both commercial and recreational and is valid on all public waters that are open to shipping, with the exception of a number of waterways on which different rules apply, such as on the (Upper and Lower) Rhine, the Lek, the Waal and the Pannerdensch Canal. Here the Police regulations for the navigation of the Rhine (RPR) apply. The differences are due to the busy commercial shipping in the RPR area, causing small vessels to have relatively fewer rights than in the BPR area[11].

Figure 4 provides an overview of the different navigational rules (regulations) that apply on the waterways in the Netherlands. It should be noted that these rules apply almost everywhere, with the BPR as a starting point.[12]

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[9] The Wadden Sea also belongs to the inland waters.
[10] https://wetten.overheid.nl/BWBR0003628/2017-01-01
[11] https://vaarbewijsfilmpjes.nl/verschil-bpr-en-rpr
[12] Only non-public waters that are not open to navigation would not be covered by the BPR.

Figure 4 Overview of applicable waterway regulations on Dutch waterways[13]

Article 6.23 of Chapter 6 of the BPR is specifically designed for ferries and is relevant to take into account for the development of automated systems for ferries. This part of the BPR reads as follows[14]:

1. *"A ferry may only depart from, turn around or cross the water after it has ascertained that this can be done without danger.*
2. *A ferry may require the co-operation of a large vessel when departing, turning or crossing the waterway.*
3. *A small vessel must give way to a departing, turning or crossing ferry."*

A more fundamental article (Article 1.04) in the BPR, applicable to all situations and vessels, reads as

[13] https://waterkaart.net/gids/nieuws/artikel/wanneer-heb-je-het-binnenvaartpolitiereglement-nodig
[14] https://maxius.nl/binnenvaartpolitiereglement/hoofdstuk6/afdeling4

follows[15]:

> *"The skipper shall, even in the absence of explicit rules in these Regulations, take all precautionary measures which are required by good seamanship or by the circumstances in which the ship or convoy is situated, in order in particular to avoid:*
>
> a) *endangering the lives of persons*
> b) *cause damage to other ships or floating objects, or to banks or works and installations of any kind located in the waterway or on the banks thereof;*
> c) *the safety or smooth running of shipping is endangered."*

It can therefore be stated that automated systems must be built in such a way that the above articles (article 6.23 and 1.04) can be complied with. Also, of course, keeping an eye out for possible exceptions and possible future adjustments to laws and regulations that may provide more room for automated/autonomous applications.

In addition to these regulations, there may be local and regional rules such as port regulations and rules set by municipalities. Furthermore, there are Vessel Traffic Services (VTS) to coordinate shipping in traffic separation schemes, to and from ports and along a busy river. VTS can be compared to air traffic control in aviation and also uses radar. However, unlike an air traffic controller, the role of the VTS is directive and not compulsory. The VTS informs shipping, warns of imminent danger and gives advice to skippers, but cannot give direct orders concerning the actions to be taken (Onderzoeksraad Voor Veiligheid, 2019).

Next to navigational rules, there are technical requirements for inland vessels including the ferries that are considered in this report. DIRECTIVE (EU) 2016/1629 lays down the technical requirements for inland waterway vessels applying to, under which, vessels having a minimum length (L) of 20 metres and/or passenger vessels constructed and equipped to carry more than 12 passengers (Official Journal of the European Union, 2016).

The European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN), lays down the uniform technical requirements necessary to ensure the safety of inland vessels. References to ES-TRIN are now included in the legal frameworks of the EU and the CCNR (respectively DIRECTIVE (EU) 2016/1629 and Rhine vessel inspection regulations).[16] Chapter 19 contains special provisions applicable to passenger vessels dealing with technical aspects concerning the hull, stability, propulsion, etc[17].

Vessels that are carrying less than 12 passenger and are shorter than 20 metres are not obliged to comply with ES-TRIN. These vessels are subject to almost no legal obligation, not even if they are used to transfer passengers on a commercial basis. These vessels are not subject to compulsory licensing, no VHF radio or radar requirement, only marginal lighting, etc. Nevertheless, these small vessels are also allowed to cross busy and large waterways (main transport axes) with passengers. The market for small ferries is a growing one and to contribute to a safe navigation, three Dutch associations developed together a guidance on minimum nautical, technical and manning requirements (Landelijk Veren Platform; Centraal Bureau voor de Rijn- en Binnenvaart; Vereniging van Nederlandse Gemeenten, 2013)[18]. This provides guidance to operators, municipalities and other waterway managers on crew requirements and minimum safety requirements for small ferries. Municipalities

[15] https://maxius.nl/binnenvaartpolitiereglement/artikel1.04
[16] The Danube Commission also decided in 2017 to recommend the standard in its international instruments and the International Sava River Basin Commission intends to create a reference to the standard in its legal framework.
[17] https://www.cesni.eu/en/technical-requirements/
[18] The small ferries that are self-propelled by manual power along a cable are not considered.

and other waterway authorities are also free to formalise the requirements of this guide and to include them in the regulations (bye-laws) they deem appropriate.

Concluding, in contrast to the great diversity described in the previous chapter, the navigational and technical requirements regulations are more uniformly applicable. In terms of the technical requirements though, there is a distinction between ferries that carry more than 12 passengers/are longer than 20 metres and ferries that do not fit into this category. At the moment, ferries with automated functionalities should consider these regulations. There are possibilities for exceptions and future changes in regulations are to be expected. The following chapters explain this in more detail.

SUMMARY

This chapter elaborated upon an extensive stocktaking exercise to gain insight into how the sector is structured and made a categorisation of the ferry services sector based on:

- Type of transfer
- Ferry model
- Sailing period and sailing times
- The function performed
- Sailing environment and conditions

In addition, also the navigational and vessel-specific technical rules are being elaborated upon. This exercise shows a variety of types of ferries that are also used in different ways and waterways. In contrast, the regulations apply more homogeneously. This categorisation and the regulations are relevant to consider for the challenges towards the implementation of autonomous vessels. This especially accounts for the technical challenges, since these challenges will not exactly be the same across the sector. For example, the challenges will be different for a foot ferry transferring pedestrians only that cannot manoeuvre freely as compared to car ferries that can manoeuvre freely and operates on salt water.

5. Benefits of Autonomous Sailing

Benefits of Autonomous Operation of Ferries

Autonomous sailing is currently in its infancy phase in the Dutch and overall European Inland Waterway Transport sector. However, it is receiving a lot of attention and a number of frontrunners from the sector are already working on research projects, pilots and the application of systems (e.g. sensors and cameras to monitor situational awareness) that fit within the pathway towards autonomous sailing. The CCNR listed the relevant pilot and research project in the field of autonomous sailing in IWT.[19]

As with all innovations, there is an interplay of push and pull factors that stimulate the uptake of autonomous sailing in inland shipping. There is a technology push from the technology developers, but there is also a certain market pull from the IWT sector itself. Autonomous operations can be a solution for the ageing problem and the shortage of personnel in the sector, but it can also contribute to the transition towards zero-emission IWT through more efficient operations.

There are in general a number of advantages to autonomous operations, some key advantages can be enumerated as follows[20]:

- Increased productivity of personnel on board/on shore
- Elimination of the human error factor leading to improved safety and reduced accidents.
- Improved navigational traffic security due to more and easier surveillance, monitoring and control.
- Efficiency gains due to efficient navigations on waterways, lock passages, etc.
- Reduced energy consumption and emissions

These are generally accepted potential benefits of autonomous operations in general. For ferries, this can be further refined, as some of these benefits apply more clearly than others.

Although various potential benefits of autonomous shipping exist, they will not all be reached within the same implementation, especially early on. It is more likely that a use case emphasizes a selection of traits and improves those by automation, while other measures of performance are acceptable, but not necessarily significantly improved. For example: An autonomous ferry, in service 24/7, which does not consume less energy per crossing than a human operator is not a problem for this specific use case if energy consumption was not the goal but rather availability.

Productivity of personnel

Productivity of personnel is a key benefit of d/autonomous operations. By automating ferry processes, the crew is no longer required on board. A smaller number of personnel can supervise operations of multiple ferries from control centres.

This is especially beneficial if the ferry has long operating hours with relatively low passenger numbers. Several shifts are normally required for operation, and the crew costs per transported passenger can be prohibitive to cost efficient operations.

Achieving this productivity gain also poses its own challenges. Many ferries operate with only one or two crewmembers, and the productivity gain therefore only applies if the ferry can operate without crew altogether. To achieve this would call for autonomous operations, potentially with a supervisor in a shore control centre who only intervenes in exceptional cases.

[19] https://automation.ccr-zkr.org/1000-en.html
[20] Based on https://www.mdpi.com/2071-1050/12/7/2789/pdf

Eliminating human error

Elimination of human errors is equally relevant for ferries, since the transport of passengers, often in crowded environments in most cases calls for a higher level of safety than conventional cargo operations. The human error appears to be the major contributor to accidents with ferries, and with automated systems this human factor error could be eliminated. Accidents do occur with some regularity in the ferry service sector. Accidents involving two vessels are rare. They are mostly accidents between ferry and infrastructure. Accidents involving passengers occur mainly when mooring and sailing away, for example when a cyclist or pedestrian tries to board at the last minute.

When the technology is mature and approved by regulatory instances, autonomous ferries will be safer compared to ferries in conventional operations.

Navigation security and efficiency, energy consumption

Improved navigational traffic security is often less relevant in ferry operations, since most ferries operate in either quiet inland waterways or in areas with recreational traffic, which is much less organized in any case. It is unlikely that other traffic in the area can be integrated in a digitized traffic management system as may be possible with professional, commercial shipping.

Efficiency gains in navigation will have a limited impact on ferries, for which routing and speed often cannot be optimized by automated route planning. Also, eliminating crew facilities will have a very limited impact on the size and design of ferries. This also entails that reduced energy consumption is difficult to achieve using autonomous solutions alone.

Towards a Vision for Autonomous Ferry Operations by 2030

The previous chapters introduced the ferry service sector and the concept of autonomous sailing. Within this NAVIS project a workshop[21] and various interviews were conducted to get the necessary insights into the expected benefits and challenges related to autonomous sailing. These benefits and key challenges were used by the Netherlands Forum for Smart Shipping to formulate a vision for autonomous ferry operations, i.e. that by 2030 autonomous operations in the ferry services sector will no longer be an exception, but surpass the demonstration phase and be commercially viable and adopted by the sector.

Firstly, it is expected that by 2030 it will be possible to deploy autonomous ferries with a human in the loop and to have remote controlled operations with a shore control centre.

Depending on the exact type of ferry and the organization operating it, there may be financial benefits for automated operations due to reduced personnel involvement. This will for example apply to ferry service providers operating multiple medium sized ferries on the waterways for public transport. There will also be gains in efficiency, reliability and safety. Examples are remote or autonomous pilotage and control of vessel processes which will increase efficiency, reduce human error and monitor vessel processes by automated systems and allows better planning of maintenance and system/design analysis (data driven operation).

Furthermore, there is a threat that by 2030 there will be a shortage of qualified crew members for ferries. Ferry operations using a shore control centre can offer a solution in a scenario where ferries are underutilized or unable to perform economic activities due to a shortage of personnel.

Lastly, public bodies may be willing to invest in autonomous ferries for environmental and safety reasons, and to ensure continuity of public transport on water in the future.

[21] The NAVIS workshop took place on 17-05-2021. The participants represented NMT, Damen, MRDH, Captain AI, Landelijk Veren Platform, Holland Shipyards, TU Delft and EICB.

Key assumptions

This vision is based on several assumptions made with regards to the benefits and key challenges. The following key assumptions were identified in collaboration with SMASH![22]:

- A positive business case exists for autonomous ferries by 2030.
- Public bodies such as municipalities and provinces show a willingness to invest in autonomous ferries.
- By 2030, the majority of new ferries will be battery-electric driven.[23]
- System automation increases the safety of ferries and fewer accidents occur.
- By 2030, passengers will trust a ferry without a skipper.
- By 2030, there will be no legal barriers to the deployment of autonomous ferries.

These assumptions were discussed during the NAVIS workshop. Moreover, additional in-depth interviews were conducted with both project partners and external partners. Most of these assumptions represent obstacles to be overcome, which are discussed in the following chapter. The existence of a positive business case and the role of municipalities deserve some further clarification here.

A positive business case, Electric Ferries and Safety

Existence of a positive business case for ferries will (have to) be based on much more factors than just a lower cost of autonomous ferry operations. Finances for inland ferries are quite often supported by public bodies, as proceeds from ticket sales alone are frequently insufficient for pure commercial operations.

Public bodies like municipalities and provinces don’t currently have specific support programs to directly stimulate automated and autonomous operations in the ferries service sector as there are policies for greening (i.e. GHG and pollutant emission reduction) for example. However, there are of course policies to stimulate innovations in general and the development and application of automated technologies are part of it.

Public bodies may also be willing to invest in autonomous ferries for other reasons. There is currently a trend towards battery-electric ferries. There is also an expectation that most new ferries build in 2030 will be battery-electric. Ferries often operate in densely populated areas and investing in battery-electric propelled ferries will contribute to a reduction of GHG emissions and pollutant emissions in urban areas. Projects that combine electric driven ferries and automated systems contribute to the government’s goals of reducing emissions and thus qualify for the various greening incentive programmes. Ferries with an electric platform as compared to conventional ferries will also be more suited to be equipped with an installation for autonomous operations.

Finally, investing in ferries without skippers on board may be a way for public bodies to ensure continuity of public transport on water in the future, given the impending shortage of qualified staff by 2030 for ferries. However, public organisations must also maintain a sensitive balance between encouraging automation and preserving jobs.

In addition to these benefits, there are also several challenges which have been briefly touched upon, concerning the technique, laws and regulations and social acceptance. The following chapter discusses this in more detail.

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[22] Brainstorm held with SMASH! cooperation partners on 04-05-2021.
[23] Battery-electric driven ferries lend themselves more to the application of autonomous systems.

6. Conditions, Considerations and Challenges

Technical Challenges

The technical challenges which are to be resolved to make autonomous ferries possible can be divided in several categories, following the structure of the SMASH! Roadmap for smart shipping[24]:

a. Navigation & guidance
b. Ship internal systems
c. Communication
d. Remote & shore control
e. Waterways, locks & bridges

Navigation & Guidance

To establish safe autonomous navigation and vessel route guidance systems, the functional requirements and performance standards of these systems need to be established to an objective and consistent standard. The behaviour of these systems will be compared against the behaviour of human operators and against collision regulations which are currently not framed in a suitable manner for use by machines. The performance standards for equipment used for gaining situational awareness and situational understanding are currently unavailable. It is currently not known how good is "good enough", and quantified safety standards for navigational safety are lacking. Development and testing of such standards is essential input for the development of new regulatory instruments, both in the EU and in national legislation.

- Journey and route planning: While various journey-planning and route-planning systems are being tested for application on autonomous vessels, these need to be developed and tested against functional and performance requirements as a prerequisite to regulatory and market acceptance.
- Situational awareness: Autonomous navigation systems rely on new sensors to build up a situational awareness of the environment around them. These sensors may be on the vessel, on other ships or even on shore. Development of these sensors is ongoing, but their performance needs to be measured against standards which are currently not available for their purpose in supporting autonomous navigation. Furthermore, when sensors are not installed on the vessel itself, but as part of the infrastructure or on other ships, the data from these sensors needs to be uniformly interpretable by the navigation systems. Common data standards for these sensors are currently lacking. For a small number of applications, situational awareness might not be required due to the simplicity of their operation.
- Collision detection and avoidance systems: Collision avoidance systems based on machine learning technology are under development with various companies and being tested in real environments, but it is not defined how the performance of these systems is to be evaluated or proven. To ensure market and regulatory acceptance, the functioning of these systems needs to be validated in novel ways, and this cannot be done without the sensors from which the system builds up its situational awareness.

Ship Internal Systems

To make the move towards autonomous sailing, the vessel's internal systems will need to be digitalised, machine-readable, and connected to navigation and guidance systems and/or remote control systems. Systems include, but are not limited to: power management, onboard hydraulics, mooring systems, actuator control (e.g. rudder) and ballast water management systems. Often these

[24] https://www.smashroadmap.com/

systems are standalone, controlled by the crew, and need to be connected to the navigation and guidance systems in order to allow for autonomous sailing. In existing vessels these systems may be analogue. Another challenge is to interconnect systems built by different suppliers. To establish safe autonomous shipping systems, the functional requirements and performance standards of these systems need to be established in an objective and consistent standard.

Communication Systems

To enable remote monitoring and especially remote control of ferries, the functionality, reliability and cybersecurity of the vessel-shore communication systems need to be substantially improved. This starts with clear functional requirements for these systems, which are dependent upon the functional requirements defined for the navigation, control and remote-control systems. Performance standards for communication and cybersecurity systems have been written by class societies, but current standards for position and vessel information are inadequate for autonomous navigation or remote control, and requirements for reliability and redundancy of these communications need to be re-evaluated.

4G/5G network reliability and safety - Communication with shore control centres significantly relies on 4G/5G networks. These networks are sensitive to cyberattacks and may not be reliable enough to guarantee the required 100% uptime. To ensure the safety of autonomous operations, especially the ones involving passenger transport, cyber-safe communication systems need to be developed.

Safe/cyber-secure connectivity - As of 2021, there is insufficient experience in designing cyber-safe/secure autonomous ferries, as these platforms have very limited deployment in pilot tests. Knowledge and experience in this field needs to be built up. Cybersecurity needs to be addressed from the perspective of system communications. Currently developed standards are adequate for partial system connectivity, but integration into a wider system of ship-shore communication is untested.

Remote & Shore Control

The application of autonomous sailing requires interaction with shore control centres (SCC). However, so far, there are no clear and standardized functional requirements for SCC in relation to ferries. These need to be defined specifically for the different types of ferries to determine how SCC can handle them and which technical systems will be required.

Waterways, Locks & Bridges

The application of autonomous sailing not only requires adjustments to the vessel itself, but also to the infrastructure. To be able to make these adjustments to the infrastructure, it is firstly necessary to get the functional requirements clear so that the infrastructure is at a level that can facilitate autonomous sailing.

- Connectivity requirements: The application of automated systems on ferries will require several conditions relating to connectivity and GPS/AIS coverage on the waterways. These requirements need to be identified so that they can be worked on.
- Digitalization infrastructure: Digitalization of infrastructure, operational and planning tools that are machine-readable and in accordance with international standards will be required for a cost-effective implementation of smart ships, but the extent of required data is not known or uniformly established, nor do the infrastructure owners have a clear incentive to contribute financially to this digitalization. Resolution of earlier obstacles and willingness could provide these standards, but the timeframe for realizing these investments may be too short for effective contribution to the market implementation.

A recurring theme in these technical challenges are the "functional requirements”. These are not “pure” technical challenges, but mostly related to engineering the technical implementation to accepted and recognized standards, so straddling the technical and regulatory domains. By focusing on the functional requirements to such systems, the designers can maintain flexibility in selecting the most appropriate technical solutions.

Challenges in Laws, Regulations & Liability

The challenges in laws and regulations for autonomous sailing are twofold: challenges due to existing policies from public bodies, and rules concerning liability that do not, yet, take into account the developments in the field of autonomous and automated sailing. Currently, both public bodies and insurance companies set requirements that must be met, which forms a bottleneck for the application of autonomous sailing, also specifically for the ferry service sector. The sections below are based on expert consultations with experts form the Ministry of Infrastructure and Water Management and maritime law experts.

Laws and Regulations

As far as government regulations are concerned, in general, the biggest bottleneck for autonomous sailing without crew on board is the **minimum crew requirement**.[25] In the case of ferry services in the Netherlands, the regulation “Binnenvaartregeling“ (BVR) and ”Regulations for Rhine Navigation Personnel“ (RPN) are the relevant regulations that prescribe the minimum crew requirements. The BVR also contains technical requirements that expressly require or presuppose the presence of crew on board the vessel, e.g. related to the presence of manually operated equipment on board or the design of the vessel that relies on personnel staying on board.

However, the BVR offers the possibility of granting exceptions or exemptions. The possibility of granting an exception is very well suited for enabling experiments with autonomous vessels for a limited duration. It is relevant to stress the limited duration of an exception as it is not the intention to renew and/or reissue an exception for normal operations. An exemption, on the other hand, may be for the longer term and has a categorical character. An exemption refers to a category such as a group of vessels that receive an exemption because they cannot comply with the regular regulations. There is, for example, an exemption for the Amsterdam canal boats, which have a separate kind of license, a categorical exemption. However, the nature of an exemption is not suitable to grant for innovations such as autonomous ferries and is therefore not an option in this case.

Regarding the international playing field, recently the CCNR has also been able to grant exceptions for experiments with autonomous sailing vessels on the Rhine and waters covered by the Mannheim Convention.

However, contrary to exceptions, there is a need for a structural solution. Certain matters must be legally anchored, both at national and international level, and therefore regulations must be adapted (e.g. BPR, BVR, RPR and RPN).

In addition to crew requirements, ferries must meet **passenger safety requirements**. This is an additional complexity compared to freight transport. Ensuring passenger safety is regulated by law. These are included in Annex 3.6 of the BVR and Annex 3.7 for ferries of the BVR. The BPR also guarantees the safety of everyone on the water, so the safety aspect is also incorporated in the BPR and must be complied with. The inability to demonstrate that this safety can be guaranteed will be a bottleneck to obtaining an exception during an experiment, let alone changing regulations. It is therefore relevant for future amendments to laws and regulations that it can be objectively demonstrated that the transport of passengers by autonomous ferries without a captain on board is as safe as transport with conventional ferries. This is currently the biggest issue as regards the safety aspect, to legally ensure that operations are as safe or even safer as when someone is on board. Is it possible to make it technically so safe that

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[25] This is being addressed in both the interviews with experts and in the study "Juridisch Onderzoek Smart Shipping" https://www.rijksoverheid.nl/documenten/rapporten/2020/03/03/rapport-erasmus-school-of-law-juridisch-onderzoek-smart-shipping

no crew needs to be on board of the vessel? An intermediate option is of course that someone can still intervene remotely, i.e. to have a human in the loop, even with 'autonomous' operations.

As regards the required adaptations to existing regulations, it can be said that a legal framework for autonomous shipping is now being developed. These processes are already underway, but at the same time, consideration must be given to the area in which this is to be done. Adjustments to national legislation such as the BPR can be made reasonably independently in the Netherlands without involvement of other states. However, amendments to international regulations such as the RPR require changes to be made at CCNR and CESNI level with the Member States concerned.

For the national policymakers it is important that use cases are developed in cooperation with the Ministry of Infrastructure and Water Management and Rijkswaterstaat. This will provide the necessary flow of information to policy makers, who in turn can make and/or adjust policies and regulations in an informed manner and timely manner.

The expectation from policy makers is that there will be a mix of conventional and autonomous vessels by 2030, indicating that there will be probably less legal barriers for operations with vessels automated to a great extent and remote controlled operations than currently applicable. It is not expected that fully autonomous systems without a human in the loop will be possible for the time being.

Liability

As far as liability is concerned, this falls within the remit of the insurers. Existing insurance packages for ferry services and waterborne transport in general, do not take into account the possibility of autonomous sailing and its impact on risk distribution and liability. This is the biggest bottleneck for autonomous sailing as far as the liability issue is concerned. The question that matters in this case is what the risk allocation will look like, and who will be liable in the event of an incident.

This is relevant as incidents also occur on ferries. In the case of ferries, however, the type of incident generally differs from that of freight transport. One example is cyclists who try to board at the last minute in an unsafe manner and with the consequences that this entails. Incidents involving self-service ferries (i.e. chain or cable ferries without a skipper) are very rare. If something goes wrong with the hardware, the owner is to blame. If passengers make injudicious use of the ferry, the passenger is responsible.[26]

In principle, the owner of the vessel is in charge and thereforeliable under all treaties. This may also include the operator who is not the owner of the vessel.[27] If something goes wrong with e.g. a largely automated vessel, the insurer, together with the vessel's owner, will look into whether the software producer can be held liable, if the software has a cause in the incident and if there is product liability. On the other hand, of course, the software producer also wants to limit his own liability.

When the captain is disembarked, it has to be considered whether the shipowner is still liable or whether the software producer should be. However, the complete removal of a captain from the vessel is difficult from the perspective of the insurers. There will always have to be someone interfering. It will not be possible to get it accepted socially that there is a situation without control over the vessel, either on the vessel itself or from the shore.

The situation is different with a shore-control centre. Then it depends on where the vessel and the shore control centre are located. If both are in the Netherlands, then there are possibilities for taking out an insurance package. It is important that action can be taken where the control of the vessel lies when incidents occur. The control of the vessel, i.e. the shore control centre in this case, must be where the

[26] Based on expert consultation with maritime law experts

[27] In case of IWT the operator must then be in possession of a proof of authorisation ("bewijs van toelating") such as the Rhine Navigation Certificate (Rijnvaartverklaring).

vessel is registered.[28] As far as the shore control centre is concerned, it is required to have the top of the bill in terms of personnel and qualifications, assuming that there will be fewer personnel controlling vessels from shore.

The insurer's assessment is made on a case-by-case basis. Aspects that are being taken into account are the type of vessel, the owner of the shore control, qualifications of the shore control, etc. Especially in the case of ferries, safety will be very important. A highly autonomous ferry with a human in the loop, needs to be safer than a conventional ferry. The insurer will first look at how the shipowner can be insured, then at whether the operator/shore control can be included too.

However, in terms of liability to the outside world, the owner or operator remains responsible. The public, criminal and contractual liabilities towards counterparties are designed in such a way that it is not possible to refer to the shore control centre or the software supplier in case of an incident. One then simply enters contractual liabilities unknown to the outside world. The owner or operator will always be the party to be addressed in the event of an incident. How the shipowner or operator subsequently arranges things with shore control is their responsibility.

For the development of new insurance products, it is important to involve insurers in pilots as early as possible in the process. This will help to gain the necessary knowledge and to exchange feedback.

Business Case Considerations

Although originally set up for seagoing vessel, DNV has created a useful overview of which factors come into play for defining the business case for automated or autonomous systems (Vartdal et al., 2018). Various parties within the project consortium have been asked to provide input on costs associated with ferry autonomy. The following aspects are considered:

Capital Costs

If ships could be made fully unmanned, costs associated with setting up systems and structures for sustaining people on board can be significantly reduced. For ferries this is not the case, since the main purpose of ferries is to bring people across waterways. On the other hand, hardware such as sensors, communication systems, PLCs, actuators, and software come at a cost as well. The costs depend on various factors, among which:

- Complexity of automation and level of autonomy required: Investment costs can be significantly reduced if autonomous operations are combined with remote control or (remote) supervision.
- Size of vessel: The amount of cameras and sensors depends on the size of the vessel, as well as e.g. the size of actuators.
- Operational considerations: for instance, vessels will require more expensive (e.g. thermic) sensors if they require operation during night time.
- Economy of scale: If investment costs in new developments can be spread over various vessels, costs per vessel can be significantly reduced.

Given the wide range of applications, it is impossible to give one single estimation for the investment costs for automated systems for ferries. However, multiple project partners have provided input [29] for investment costs, and these confirm that investment costs can vary widely, dependent on type of

[28] Public responsibilities also play a role in this. A flag state can be called to account if an incident occurs when the rules of control are not properly regulated but the flag state does allow ships to sail autonomously. For more information see Article 94 UNCLOS – Duties of the flag State.

[29] All numbers in this section are based on input from project partners, external experts, and input through the SMASH! Network. As the main text says, costs are very dependent on size of ship, application, extent of automation, sailing environment, etc. Numbers in this section should therefore be used with utmost caution.

application and extent of automation. One thing is clear: eliminating *all* crew from the vessel comes at a significant cost. Currently, most emergency systems are dependent on human interference, like lowering an anchor, or closing valves. Extending automation to these types of systems, in a redundant way, in addition to navigation, will be very expensive.

Investment costs for just hardware costs can easily lie in the region of 100.000 euro for small vessels, plus another 100.000 for algorithm development for (not fully) automated functions. If thermal cameras are required for nighttime operation, another 100.000 needs to be added to the estimation. For larger vessels, these numbers can easily be twice as high. On the other hand, many of the larger vessels already are equipped with necessary systems like radar, AIS, and IMU. Powerful computers with GPU for camera images are still required, as well as expensive communication systems (±25.000 euro).[30]

Investment costs for large ferries with high autonomy levels are expected to be several millions. This does not include the development of remote control centres, which can easily add 0.5 to several million to the equation, dependent on the specifics.

Operational Costs

Crew costs will obviously be affected by automation and autonomy. On board crew could be reduced, and for vessels with a high automation level the competence of crew could also be lower, resulting in the possibility to hire less qualified and thus less expensive crew, and could form a solution for shortage of crew. If ferries were to become crewless, crew in a remote control centre must often still be accounted for. This also shows that the crew costs for small ferry services may not be significantly reduced as crew will still be required in most cases. For larger ferry operators running multiple vessels, benefits on this cost item may be more interesting.

Additionally, costs for repairs may be significantly reduced as well, if the technology matures well and autonomous ships prove to be less prone to accidents. The development of automated systems also goes hand-in-hand with predictive maintenance, resulting in lower maintenance costs on the long term.

Developments for autonomy and automation often go hand-in-hand with optimization of operational processes, like routing optimization and predictive maintenance, opening further opportunities for reducing operational costs.

An increase of operational costs comes from the fact that software providers will charge subscription costs for keeping software up-to-date and maintained. The distribution of costs between subscriptions and initial investments depend on the supplier's business model (I.e. investment-heavy or subscription-heavy).

Additionally, having additional systems on board obviously also creates more systems to maintain, with its associated costs.

Added Income & Value

Next to a reduction in operational costs, there are added benefits of autonomous ferries in the following areas:

- Ferries could be in use 24/7, as they are not dependent on staff availability.
- Ferries could become a more reliant link in the public transport system, increasing use.
- Distant areas could become more easily accessible, increasing land values, business opportunities, etc.
- Development & maintenance of such high-tech systems creates job opportunities.

[30] All mentioned cost estimations are based on discussions with project partners.

- Autonomy and automation may be (part of) the solution for crew shortage, which is expected to increase over the coming years.

Most of these benefits are intangible and impossible to put a number towards in term of value. It is often the difficult task of (local) governments to compare these benefits to the costs, which makes it hard to set up a solid business case for autonomous ferries. In terms of just monetary costs vs income, the case for autonomous ferries is often a negative one, especially on the short term where investment costs are still reasonably high due to a high degree of development involved in new applications. On the long term, it is expected that these costs will go down significantly, while benefits will increase due to improved algorithms and areas of application, further reducing costs for e.g. staff, maintenance, and perhaps fuel.

Social Acceptance

Whether passengers will, by 2030, have enough trust in boarding a ferry without a skipper on board will be difficult to predict. Ensuring social (public) acceptance for automated and autonomous transport systems is crucial for the implementation and adaptation of these systems[31]. This also applies to passenger transport by water with ferries.

There is no or very little research on social acceptance of autonomous ferry passenger transport services on inland waterways. However, existing literature that focuses on other modes of transport and essential research on autonomous mobility, already provides relevant insights that are also relevant for passenger transport by ferries on inland waterways.[32] For this purpose, an expert consultation took place with Prof. Dr. Bert van Wee of TU Delft.

Based on this consultation, three key variables are identified that have an influence on the social acceptance of autonomous transport, these are:

- perceived safety of passengers
- perceived safety of others
- level of service

Passengers need to perceive the transport per autonomous ferry as safe, otherwise there will be no trust and no or little use will be made of the transport services.

Second, others such as other waterway users also need to perceive the system as safe, otherwise this may lead to resistance from this group for the deployment of autonomous ferries. This is important, as it is expected that autonomous vessels and manually operated vessels will need to co-exist for a long time.

The distinction between fully autonomous (in the “self governing” meaning of the word) and automated operations is important here. It will be more difficult to safeguard the perceived safety of transport on a fully autonomous ferry than on an automated ferry with supervision from a shore control centre.

The third relevant key variable is the level of service. This relates to the transport service that may or may not improve in quality, the price of the service and basically the entire offer towards potential and existing passengers which will have an impact on the eventual social acceptance.

The perceived safety of passengers and others is subjective and more difficult to measure as compared to the objective safety. The objective safety can be measured through objective data such as number of

[31] https://www.sciencedirect.com/science/article/abs/pii/S2543000920300032
[32] It can be argued that autonomous/automated water transport is less complex than autonomous/automated road transport, for which the conditions are more complex and less predictable. In that respect, autonomous/automated waterborne transport is between autonomous/automated road transport and rail/air transport in terms of complexity.

accidents, material damage, personal injury, etc. The perceived safety on the other can be measured through surveys or other methods such as behavioral observation, heart rate variability, etc. Such measures are for example also applied throughout the pilot test of the FERRY in Koudenhoorn.[33] This pilot is also a good example of a small-scale highly automated ferry service concept being introduced to the market, giving the public a chance to get to know it and get used to the concept.

Communication is essential and has a significant impact on perceived safety and eventually the social acceptance. With communication, attention can be paid to the process before autonomous ferries are deployed and the communication from the moment they become operational.

Before the operationalisation stage, it should be clearly communicated why there is a need for autonomous ferries on inland waterways. This can be done by zooming in on the advantages, such as possibly higher safety, cheaper service, more frequent service, more efficient, etc. as compared to traditional ferry services. It is also important from whom this information comes, who should not be an interested party. Ideally, this information should come from an independent party such as the government or an independent research agency that has researched the automated/autonomous transport system. There should also be an opportunity for the public to ask further questions to independent parties who report on this.

It is also important that the communication is understandable and careful. If, for example, the word "dangerous" is included in the communication, even if it is in relation to "the system is not dangerous", people find it scarier.

From the operationalisation stage onwards, it is important to share, for example, experience figures with the public. If there are good experiences compared to the benchmark with traditional ferry services, this should certainly be communicated.

Furthermore, the communication of the ferry itself during operations is also of importance. The ferry must be able to communicate with other objects on the water (e.g. other vessels, canoe's, swimmers, etc.), for example, to indicate the intention, this could be done with lights and arrows. In case of ferries, it is also relevant to look into the communication with passengers on board of the ferry. Trust can be created by means of various instruments, for example by placing screens on board so that passengers have a clear view of the people in the shore control centre who are steering the ferry or who can intervene in certain situations. The installation of an intercom so that passengers can also communicate with the shore control centre during possible calamities also contributes to gaining confidence.

An important final recommendation is to try to get a grip on media attention. If the media portray the concept as a dangerous experiment, there will be a huge disadvantage for the further roll-out of the system. If the media is positive about it, this has a huge impact on how people think about it.

[33] https://smashnederland.nl/nieuws/smash-op-werkbezoek-bij-ferry/

7. The Road to Automated Sailing

The SMASH Roadmap for Inland Ferries

To get an overview of all the steps and obstacles to the identified vision of autonomous inland ferries, the timeframe and sequence in which these are to be addressed can best be summarised in a roadmap. For this, reference is made to the Smart Shipping Roadmap recently drawn up by the Netherlands Forum Smart Shipping (SMASH!). [34]

The roadmap has so far been drawn up for three use cases, namely short sea, inland shipping (goods transport) and inland ferries. The process to arrive at a roadmap for the ferries case is the result of intensive cooperation between SMASH! and the NAVIS project. The roadmap for the ferry case contains eight themes in which bottlenecks are listed that need to be solved in the period towards 2030 in order to realise the 2030 vision. The eight themes are:

- Skills and industry acceptance
- Liability and industry acceptance
- Implementation and market uptake
- Legislation
- Navigation and guidance
- Ship internal systems
- Communication and security
- Remote and shore control

To provide an impression, Figure 5 provides a snapshot from the page with the themes and challenges for the ferry use case. The roadmap clearly identifies challenges per theme. The majority of the issues addressed in this roadmap are addressed in chapter 6 of this report.

[34] The roadmap was launched on 3-11-2021 during Europort in Rotterdam. The roadmap is digitally available via the website www.smashroadmap.com

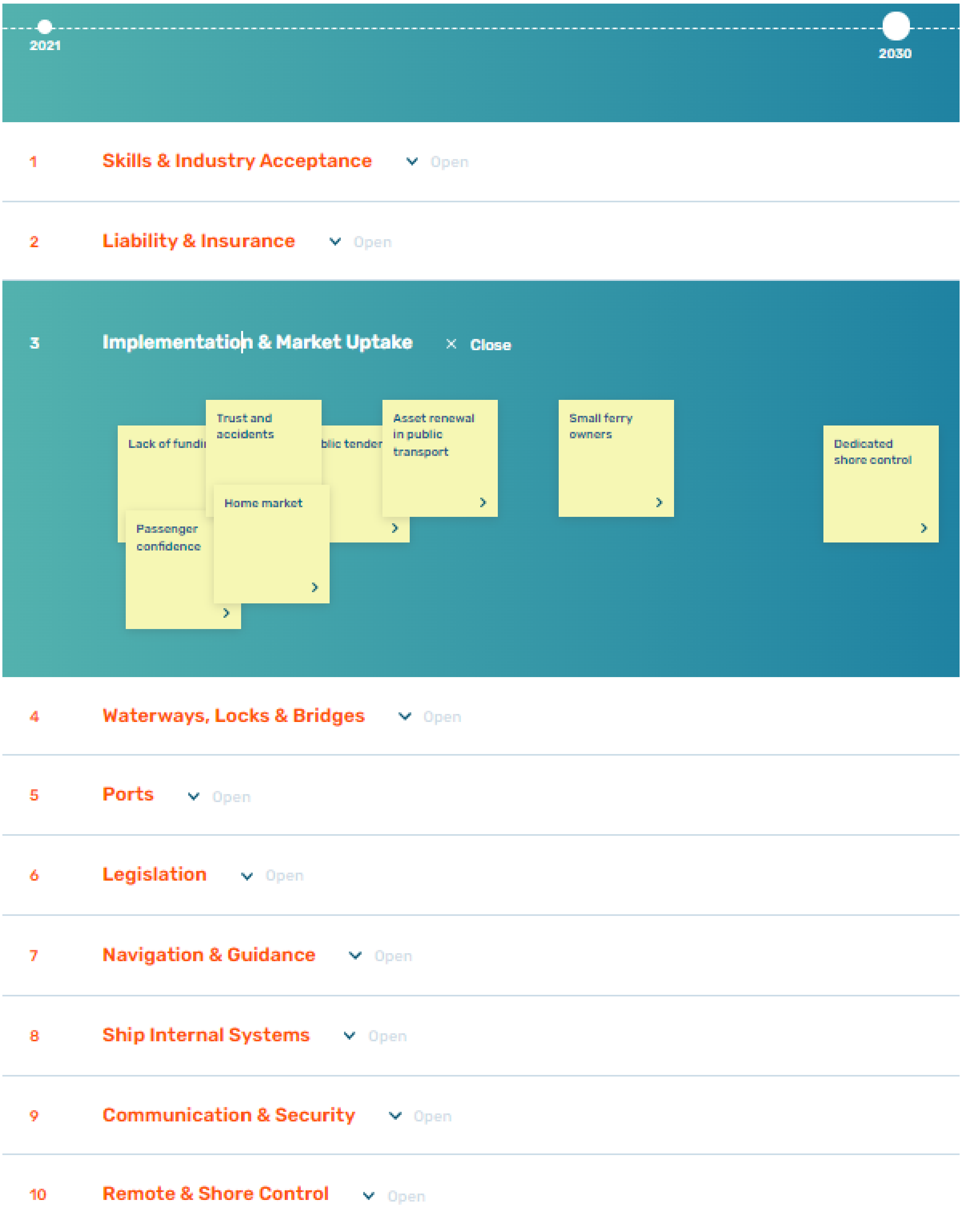

Figure 5 Snapshot of the SMASH! Roadmap for inland ferries

Key Challenges

The SMASH roadmap identifies the following key challenges:

The market for inland ferries is relatively small, mainly from a financial perspective. Therefore, technical developments depend upon the market implementation of autonomous sailing systems (both ship systems and onshore) in other sectors to make technical developments worthwhile for innovative companies to pursue.

Furthermore, the regulatory framework is more complicated than for other inland shipping applications for the transportation of goods, as the carriage of passengers brings various additional regulatory challenges, and uncrewed operation raises more questions regarding responsibility and liability for mishaps.

As the only significant improvement in exploitation costs can be achieved by having no crew at all on these small ferries, the technical challenges of crewless operation may be the most difficult of all the analysed use cases, especially since the unattended carriage of passengers calls for additional safety measures to be in place. Safe and flawless operation is essential in building up and maintaining public acceptance and trust, and passenger trust is key to the success of highly autonomous ferry operation.

Ferry Specific Considerations

Although the roadmap was created in intensive collaboration between NAVIS project and SMASH! Roadmap team, some specific considerations have been identified throughout this project, which are not (yet) reflected in the roadmap.

Whereas the roadmap presents opportunities for automation in a broad sense, this research has deepened our knowledge for ferry-specific applications. Benefits for small-scale applications are often different than for large-scale applications. Although technical solutions may be similar between ferries and other vessels, specific for ferries is the fact that they transport people rather than goods, which means that developments in the sector will always be under extra scrutiny with regard to safety compared to other markets. For good reason, the laws and regulations for passenger vessels are strict, and this makes experimentation a complex endeavour. Having passengers on board also creates an additional factor on board: their behaviour can be unpredictable. Social acceptance is, as discussed before, an important aspect for ferries, which is (generally speaking) less the case for vessels transporting goods.

A benefit of application of automated systems on ferries is that their task is often very repetitive, and in similar conditions. For instance, communication system requirements may be relatively limited if the vessel is operating in a very limited area only. The benefits of autonomous ferries, such as a potential for 24/7 availability or being a mature part of a public transport system are often intangible and hard to put an exact number on in terms of value. (Local) governments often have to compare costs to intangible value which makes making it hard to present a solid business case.

8. Conclusion & Recommendations

Conclusion

The goal of the NAVIS project was to set up a roadmap towards autonomous ferries on the Dutch inland waterways, by identifying the benefits of, and the challenges towards this goal. And although the benefits, such as increased productivity, efficiency, and safety (given matured technology) are significant, there are still some barriers to overcome. If these barriers can be overcome, we're destined to see more autonomous ferries in the Netherlands by 2030.

In terms of technological challenges, there are 5 areas to focus on: navigation, internal systems, communication, remote/shore control, and infrastructure. In essence it can be concluded that although the technological building blocks for autonomous ferries are available, there is still a lack of (safety and technological) standards for autonomous navigation and automatic systems.

The Dutch laws and regulations currently facilitate experiments and pilots for autonomous sailing. However, no exceptions can be provided yet for uncrewed operations on inland waters, and more permanent rule exemptions are not yet available. Therefore, certain matters must be legally anchored, both at national and international level, and regulations must be adapted (e.g. BPR, BVR, RPR and RPN). To develop opportunities for autonomous sailing within these regulations, it is important that use cases are developed in cooperation with public bodies such as the Ministry of Infrastructure and Water Management and Rijkswaterstaat in the Netherlands.

In regards of liability, the owner or operator of autonomous vessels remains, in principle, responsible. The public, criminal and contractual liabilities towards counterparties are designed in such a way that it is not possible to simply refer to the shore control centre or software/hardware supplier in case of an incident. For the development of new insurance products, it is important to involve insurers in pilots as early as possible in the process. This will help to gain the necessary knowledge and to exchange feedback.

In terms of monetary value, the business case for autonomous ferries is at the moment often a negative one, especially on the short term where investment costs are still reasonably high due to a high degree of development involved in new applications. On the long term, it is expected that these costs will go down significantly, while benefits will increase due to improved algorithms and areas of application, further reducing costs for e.g. staff, maintenance, and to a limited extent fuel consumption. However, in the case of ferries, benefits often reach beyond monetary values, as added value can e.g. be found in increased availability of ferry services, making it a reliant link in the public transport system.

The last discussed item to consider towards autonomous ferries is the social acceptance of autonomous shipping: will passengers have enough trust in boarding a ferry without a skipper on board? Three key variables are identified: perceived safety of passengers, perceived safety of others, and level of service. It can be concluded that clear communication, in the broadest sense, is essential for all these three variables.

Recommendations for Future Research

Transparency and terminology

Increasing transparency of projects benefits sharing of knowledge, and it helps avoiding misinterpretation and vagueness. Transparency also helps lawmakers and insurers to get involved early on, which will help reducing the barriers in terms of law, regulations, and liability towards autonomous sailing. Additionally, as in any area of research, transparency will help the research community as a whole reach better results faster.

This can be optimized in various ways, including the use of consistent and well-defined terminology, leaving as little room for interpretation as possible. When a term does not apply to the system as a whole, it should be clear what elements it is applied to. The meaningfulness of proposals, projects, and results will become clearer if consistent and well-defined terminology is used, and methods and results are shared in a transparent way.

Multidimensional assessment of autonomy

Vessel automation has been developing for decades. Various tasks on board are already partially or fully automated. However, ship automation is often expressed along a 1-dimensional scale. It is however hard to categorize the degree of autonomy of such a vessel using various automated systems as a whole. Realizing that e.g. a ferry control system has various subtasks that can individually be automated can create a multidimensional degree of automation. This helps to categorize ship autonomy in a more meaningful way, tailored to fit the discussion at hand

Technical solutions for subtasks exist and are being commercially applied and developed. Realizing the existence of these different dimensions of autonomy and automation and steps within each of these dimensions is important to be able to split the challenge towards autonomous sailing into manageable steps.

Splitting up the process into smaller steps also helps lawmakers and researchers to split up their work into smaller and manageable size challenges towards ferry autonomy.

Interviews and Workshops

Interviews were conducted with experts from the following organisations:

- Captain AI
- Marinminds
- Damen
- Holland Shipyards
- Maritieme Academie Harlingen
- TU Delft
- Ministerie van Infrastructuur en Waterstaat
- MS Amlin
- Boonk Van Leeuwen
- MRDH
- SMASH!

Additionally, two workshops were organised to receive input in an early stage of the project. These workshops were attended by the following project participants:

- NMT
- Damen
- MRDH
- Captain AI
- Landelijk Veren Platform
- RMSC
- Holland Shipyards
- EICB
- TU Delft
- HvA
- SMASH!

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