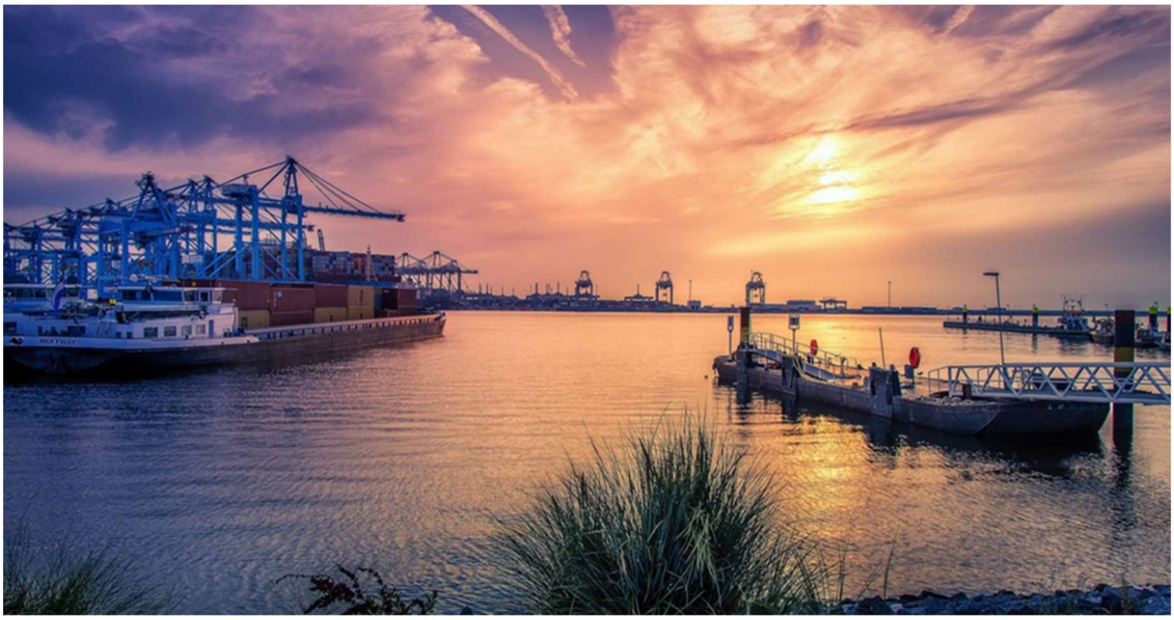
Vision Paper on automated barging

Settings sails towards the future of inland navigation



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Summary

Autonomous transport is considered to be a game changer in logistics. For the inland shipping industry, there is a need to gain more experience with different aspects of autonomous shipping. One of the aspects is to determine what the overall business case of autonomous sailing on a more detailed level for the different market segments. In this paper three research institutes cooperated with 10 inland shipping companies and with the association organizations BLN and BTB. The inland shipping companies involved represent a broad range of the inland shipping market, and include different ship sizes, operational profiles and market segments. Furthermore, interviews have been carried out with education institutes, legislative bodies and solution providers. This project has been funded by TKI Dinalog.

In the project a detailed analysis has been carried out of all work performed on board the vessel by the current crew, from which an overview has been made of the primary and secondary work process on board the vessels. This consists of the loading and unloading process, mooring and unmooring at the quay and in locks, sailing of the vessel, repair & maintenance and administrative tasks. This report provides a set of technical solutions that are being developed for each of these work processes. In order to implement these solutions, important preconditions need to be met. Firstly, the current legislation on minimum crew requirements need to be reformed into a more flexible system, such as the safe manning principle. Furthermore, investments need to be made in creating a common communication framework, investments in shore sided infrastructure and in changes in the field of education. This requires efforts for all involved stakeholders.

Contents

1 Trend towards autonomous vehicles

1.1 Overall development

Autonomisation is considered to be one of the most important research topics in freight transport. In road transport, **truck platooning** is considered to be a game changer. In essence, a platoon of two trucks is like a short train driving on the road, with the trucks driving very closely behind each other. The distance between the two trucks can really be extremely small – creating a desirable form of tailgating. Truck platooning has great potential for reducing transport costs, by lowering fuel consumption due to improved aerodynamics from reduced air resistance, eliminating the need for an attentive driver in the second vehicle, and better usage of truck assets, by optimisation of driving times and minimization of idle time. All major OEMs are currently developing trucks that are capable of platooning and since 2017 first tests on the road are taking place. **Automated train operations** is currently already common practice in urban rail passenger systems. In 2018 ProRail will perform first tests with ATO on freight trains on the Betuweroute. ATO is considered to be a way to make trains drive more efficiently and to support safe operation by erasing human errors.

Many companies and research institutes are developing concepts for introducing **Automated maritime sailing.** DNV-recently introduced a concept for an unmanned coastal vessel , the ReVolt. Rolls Royce Marine has announced to invest significantly in the development of intelligent systems. A notable first pilot project is the development of a zero emission and autonomous ship in Norway by Yara and Kongsberg. The vessel that will be delivered in 2018 will in the first phase have a detachable bridge with equipment for manoeuvring and navigation. In a next phase the ship will sail fully unmanned.

1.2 Context of inland shipping

The inland shipping industry wants to gain more experience with the possible benefits of autonomous transport. The subject is currently developed on several levels, from fundamental research on different aspects of autonomous sailing to development of first practical pilot projects. Technical development takes place on many different subjects, such as automated navigation assistance tools, development of automated mooring systems and fairway information tools. Rijkswaterstaat is currently bundling these initiatives under the flag of the Smart Shipping Challenge.

One of the aspects of autonomous sailing which needed to be developed is to determine what the overall business case of autonomous sailing. On a high level, benefits are clear. Manning costs can contribute to 50% of the operational costs of an inland vessel. Automatization of these tasks could lead to a significant reduction of these costs. However, inland shipping is a diverse market with many different operational profiles and business models. It is yet unclear what the effect of autonomous sailing has on the level of the individual ship. Autonomisation can encompass many different aspects. In integrated overview of work performed on board of the vessel is required. Development in solutions should aim to encompass all these different aspects.

This paper presents the results of a business case analysis of automatization in inland shipping. In this project 3 research institutes cooperated with 10 inland shipping companies and with the association organizations BLN and BTB. The inland shipping companies involved represent a broad range of the inland shipping market, and include different ship sizes, operational profiles and market segments. Furthermore, interviews have been carried out with education institutes, legislative bodies and solution providers. This project has been funded by TKI Dinalog.

Dit project wordt mede gefinancierd door:

V.O.F Admiral tankscheep

2 Characteristics of inland shipping

2.1 Market

Inland shipping performs an important role in the transport of freight in North west Europe (Dutch and Belgian fairways and the German Rhine). In the Netherlands, barging has a market share of 39% of all goods transported. Important market segments for inland waterway are dry bulk freight (building materials, agricultural products, iron ore and coal), liquid bulk (oil products and chemical products) and containers.

In the Rhine corridor approximately 10,000 vessels are active, of which 75% are registered under Dutch flag. Ships vary significantly in size of the vessel, market in the vessel is active and the way the vessel is operated.

The size of these inland vessels varies from 'spitsen' of less than 40 m, to coupled units with 9 barges measuring up to 285 m in length. The smaller vessels are important for transport of freight in smaller waterways. Important aspect of these different size classes is that they fall under different categories in the manning legislation.

The exploitation mode of the vessels is dependent on the size of the vessel (and number of personnel on board) and the freight segment in which the vessel is active. In container transport, time charter or long term contracts are for instance common, while dry bulk vessels often operate in spot market and in cooperations.

The inland shipping market thus is a diverse market. New concepts such as autonomous shipping can have a significant different impact for the different market segments. This will be taken into account in the following sections.

2.2 Work performed on board

2.2.1 Current legislative framework

Essential in determining the current work performed on board is the crew regulation. Governments regulate the crew regulations for inland waterway vessels to ensure the safety for transport along the fairway. Important regulations are crew regulations are described in Article 3.15 and Article 3.17 of the Regulations for Rhine navigation personnel (RPN). These regulations are in force on the Rhine. On all other Dutch inland waterways, the crew regulations as set out in the RPN has been implemented through national regulations.

The current minimum crew that is demanded depends on three different aspects:

- The operation mode of the vessel (exploitation of 12, 18 or 24 hours per day),
- the ship's dimensions
- the equipment aboard of the vessel

The minimum crew demands both indicate how many personnel should be aboard the vessel and what type of crew members need to be aboard. The current crew regulations have been negotiated between 1979 and 1986 and have been in place since 1988. Since then, only small changes to the regulations have been implemented.

Group		Crew members	Number of crew members in operating mode A1, A2 or B and for equipment standard S1 or S2					
			A1		A2		B	
			S1	S2	S1	S2	S1	S2
1	L ≤ 70 m	boatmaster................	1		2		2	2
		helmsman	-		-		-	-
		able boatman	-		-		-	-
		boatman.....................	1		-		1	-
		apprentice	-		-		1[1]	2[1] [3]
2	70 m < L ≤ 86 m	boatmaster................	1 or 1	1	2		2	2
		helmsman	- -	-	-		-	-
		able boatman	1 -	-	-		-	-
		boatman.....................	- 1	1	-		2	1
		apprentice	- 1	1	1[1]		-	1
3	L > 86 m	boatmaster................	1 or 1	1	2	2	2 or 2	2
		helmsman	1 1	1	-	-	1 1[2]	1
		able boatman	-	-	-	-	- -	-
		boatman.....................	1 -	-	1	-	2 1	1
		apprentice	- 2	1	1[1]	2[1]	- -	1

[1] The apprentice or one of the apprentices may be replaced by a deckhand

[2] The helmsman must hold a boatmaster's certificate specified by these regulations.

[3] One of the apprentices must be over the age of 18.

Figure 1: Overview of the current minimum required crew members per ship type and operating mode

The barge operators consider the current crew regulations to be no longer appropriate to the current technical possibilities and the diversity in the inland waterway fleet. As will be discussed in the next chapters, there is a demand for a more adaptive legislative framework.

2.2.2 tasks performed on board

For this study, an analysis was performed on the work schedules of 60 employees of the barge operators involved in this project. Additional input was gathered from interviews with these employees.

The analysis shows that there is clear distinction in the work that is performed by different kind of personnel and in the work that is performed during the different stages of the trip (during sailing and during loading and unloading of the vessel).

Tasks performed by the skipper

The skipper/ captain is the overall manager of the barge and works together with crew members. The skipper instructs crew members to carry out nautical, technical, operational and domestic work and also helps implementing these tasks. A main responsibility of the skipper Is save navigation of the vessel and the overall safety. As part of this task, the skipper is responsible for the sailing plan (including attention for the ballast, maximum depth of the vessel and the maximum height under bridges) navigation of the ship and communication during the trip. During navigation of the vessel, the skipper also has an educational task towards other crew members, such as training sailors in navigation or using the mariphone.

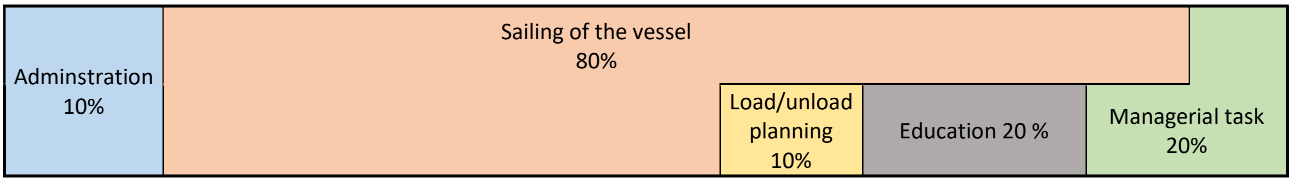


Figure 2: Time distribution of an average working day (approximately 10 hours) of a captain/ skipper during sailing of the vessel

During the loading and unloading procedure, the skipper is in charge of the operation. During loading and unloading operation, the skipper also performs administrative tasks during the loading and unloading of the vessel, such as cargo documentation, sailing hour administration, shipping documents, etc.

Figure 3: Time distribution of an average working day (approximately 10 hours) of a captain/ skipper during the loading and unloading operation

Tasks performed by the helmsman and sailor

The helmsman and sailors assist with mooring and mooring of the ship and supports the skipper during loading and unloading operations. They are also responsible for the maintenance work on the ship. In addition, the helmsman supports the skipper in the management and sailing.

During sailing of the vessel, the main work performed by helmsmen and sailors consist of maintenance tasks, including general ship maintenance (removing corrosion, applying coating to the vessel)), engine maintenance (preventive maintenance and small repairs) and cleaning. Other activities include mooring and unmooring (for instance when the ship passes locks) and navigation (as part of their education program).

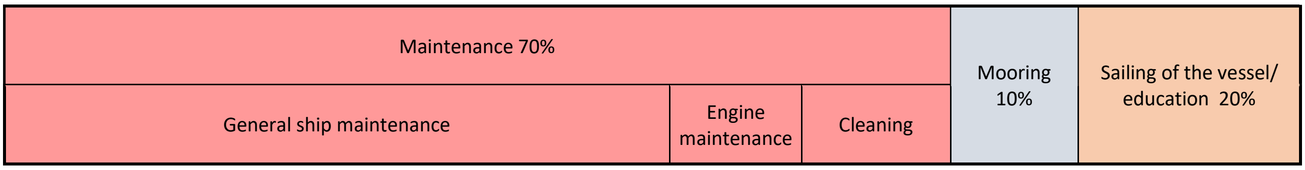


Figure 4: Time distribution of an average working day (approximately 8 hours) of a sailor during sailing of the vessel

During loading and unloading of the vessel, helmsmen and sailors divide their time with working on deck in support of loading and unloading activities and maintenance tasks. The type of activities performed by the personnel during loading and unloading differs greatly between different types of vessels (e.g. stackering containers or coupling or uncoupling nozzles for liquid bulk).

Maintenance 50%			Loading/ unloading operatio 50%
General ship maintenance	Engine maintenance	Cleaning	

Figure 5: Time distribution of an average working day (approximately 8 hours) of a sailor during sailing of the vessel

Influence of ship size and mode of operation on the workload

Operators of smaller vessels often operate in the day-trip mode of operation (mode A1 or maximum sailing time of 12 hours a day), while larger vessels, more often sail under semi-continuous (mode A2 or maximum 18 hours per day) or continuous (B or 24 hours per day) mode of operation.

As a result, many smaller vessels sail with two crew members. These are often family run business with the crew members living and working on board. Due to the smaller number of crew members on the smaller ships, these crew members have a broader range of duties than the crew members on board larger ships. The interviews showed that the broader range of tasks is not necessarily experienced as a high workload.

Larger vessels sail with 4 or 5 crew members, that often sail in two or four week shifts on board. Operators indicate that the working pressure is sometimes low because there is not always enough work for all crew members. According to the operators, with current technical measures it would be possible to sail with a smaller crew than is required by the current legislation.

The quantitative assessment of the working hours of 60 crew members shows that the division of the workload during the day is dependent on the mode of operation and the type of personnel. Captains and skippers work often in 12 hour shifts in the continuous operating mode. The varying working hours and the number of hours that the captains and skippers work outside daylight hours are considered to be mentally challenging. Sailors often only work during daytime hours and no large difference exist between the different operating modes.

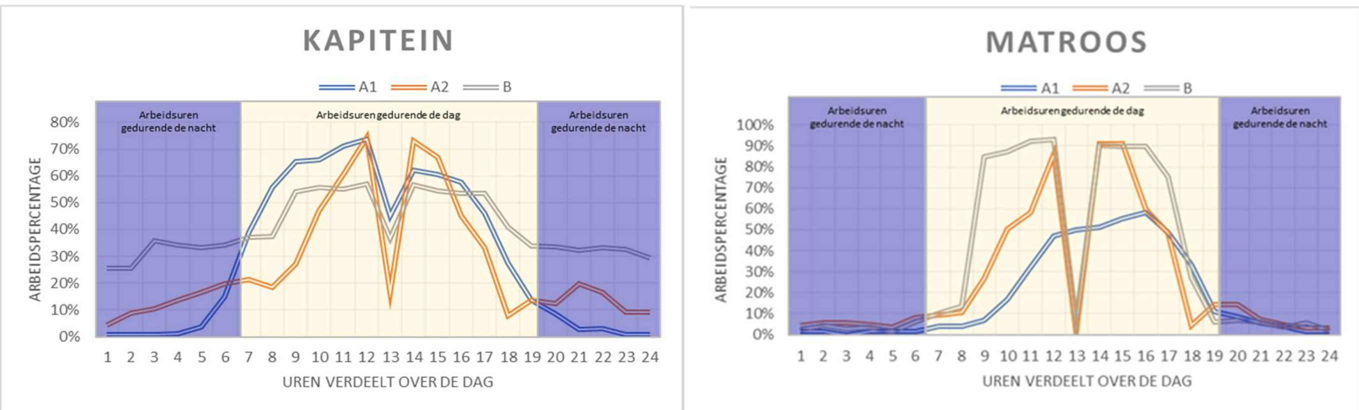


Figure 6: Working hours for captains and sailors per time of day for different operating modes

3 Autonomous shipping options

3.1 Reflection on elements to be taken into account for autonomous shipping

From the analysis of the work performed on board the vessel by the current crew, an overview was made of the primary work process on board the vessels. This consists of the loading and unloading process, mooring and unmooring at the quay and in locks and sailing of the vessel. For each of the primary processes the main responsible crew members were identified. The following figure shows the results for a large vessel in the continuous operating mode.

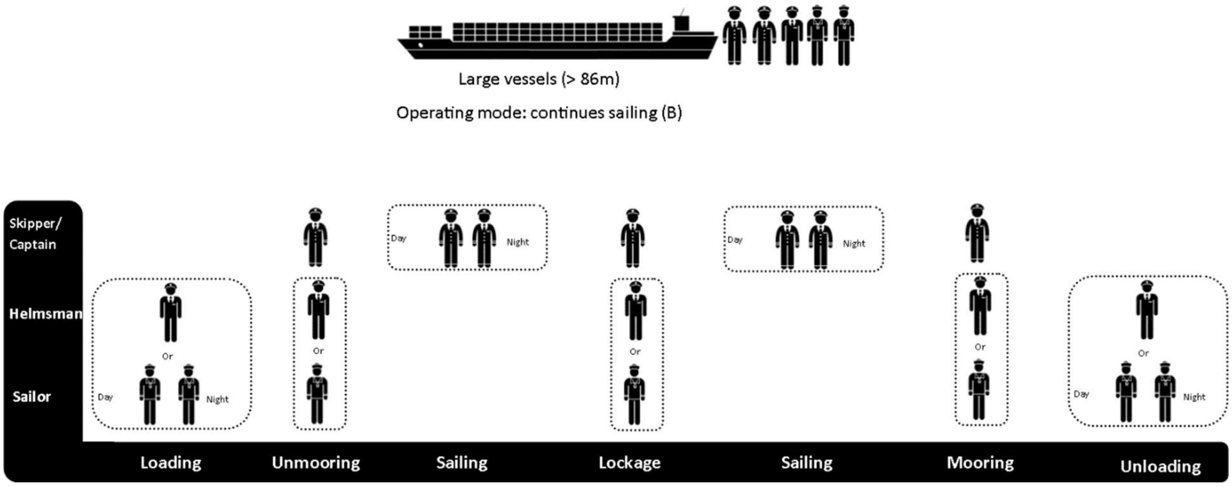


Figure 7: Distribution of the main personnel responsible for primary processes for a vessel sailing in continuous operating mode

From the figure above it can be concluded that the sailor and the helmsman primarily perform tasks related to the primary process on operating the vessel in the port, while the skipper or captain are primarily needed during the navigation process of the vessel. During unmooring, shuttling and mooring both a captain or skipper and a sailor or helmsman are required.

In this chapter an overview is presented of technical solutions that are being developed for different aspects of autonomous shipping. This chapter will present findings for both primary and secondary work processes :

- Sailing and navigation

- Mooring, unmooring and lockage

- Loading and unloading process

- Repair and maintenance

- Administrative processes.

3.2 Sailing and navigation

Given the tasks performed onboard, the daily practices in inland shipping and the state of art of the navigation equipment used in inland shipping different levels of automation and autonomy of the vessel are distinguished.

The levels of automation are;

0. Situation as is, no specific automation
1. Assisted sailing, use of a track controller; The ship follows a predefined track, specified within an electronic chart.
2. Partial automation, applying an adaptive track controller in combination with sensors, enabling speed corrections; The ship follows a predefined track, the controller monitors other ships, objects etc. and adapt speed if needed.
3. Conditional automated navigation; The ship follows a track taking into account the other ships/traffic, the environment and the objects. Complicated manoeuvres, complicated situations are handled by the navigator.
4. High automation; The system sails the ship, analyses the situations and adapts speed and course/track if needed. Monitoring of the ship and it's systems from ashore, if needed control is taken over by a controller/navigator onshore.
5. Full autonomous sailing; the ship sails autonomous and is monitored from ashore.

With respect to sailing the following aspects are taken into account: Steering and manoeuvring, adapting the speed of the vessel, monitoring and anticipating the fairway and its users, fall back performance. The following table presents an overview of the different levels.

Level	Description	Steering and manoeuvring	Adapting the speed of the vessel	Monitoring	Fallback performance
0	No specific automation	Skipper	Skipper	Skipper	Skipper
1	Assisted sailing, use of a track controller	Skipper assisted by automated systems	Skipper	Skipper	Skipper
2	Partial automation, applying an adaptive track controller in combination with sensors	Skipper assisted by automated systems	Skipper assisted by automated systems	Skipper assisted by automated systems	Schipper
3	Conditional automated navigation	Automated system	Automated system	Skipper assisted by automated systems	Schipper
4	High automation	Automated system	Automated system	Shore control center	Shore control center
5	Full autonomous sailing	Automated system	Automated system	Automated system	Shore control center

Level 0. No specific automation

This level is the situation as we encounter nowadays. The number of crewmembers is determined by the manning regulations and depends on ship size/length and sailing regime (A1 – up to 14 hours per day, A2 - up to 18 hours per day and B - continuously).

Apart of radar, an electronic chart most of the inland ships have an autopilot to control the rotational speed. This autopilot controls the rudders and is used when sailing on canals and rivers. Inland ships have additional bow thrusters for manoeuvring at low speed.

Level 1. Assisted sailing, use of a track controller

In this situation the navigator/skipper defines a track in an inland ECDIS. A track controller or track pilot controls the heading of the ship, the skipper sets the speed. If needed the skipper takes over for example dealing in situations with other traffic or unexpected events. The manoeuvres in the harbors and near quays are also performed by the skipper.

This level of automation already provides the opportunity to relieve the (sailing) task of the skipper in situations where the ship sails on a longer stretch without stops. Track pilots are already introduced by the industry.

Level 2. Partial automation, applying an adaptive track controller in combination with sensors

The use of sensors is the key element in which this level differs from level 1. Given these sensors connected to and integrated in the track controller they enable controls for speed adjustment. In this situation the skipper more and more monitors the situation and is able to relax and to prepare loading and unloading operations and other administrational tasks. The sensors (via the controller) will send an alarm in case human control is required. In this level the track controller is synchronised on the smart phone.

Level 3. Conditional automated navigation

The ship follows a track taking into account the other ships/traffic, the environment and the objects in the relevant environment. The controller is able to adapt the track if the situation, if the traffic situation demands. Besides the information exchange with terminals is improved and optimized. If applicable in the planning of cargo flows the typical constraints of the ships involved are taken into account including sequence of loading/unloading and stability requirements. Such extensive information exchange requires trust between parties involved and a high level of security with respect to confidentiality, integrity and availability.

Level 4. High automation

A controller aboard sails the ship, sensors provide input from the different subsystems aboard and provide input with respect to environment, objects and other traffic. In this stage solutions are added in order to pass bridges and locks without human intervention. The ship and it's systems are monitored from ashore and the ship is taken over by a skipper in the onshore fleet control center if a (too) complicated situation and/or manoeuvre demands this. This level imposes high requirements on the provision of information at the onshore control center. In case human intervention is needed the shore-skipper should be provided with an accurate overview and all relevant details to handle the situation.

This level of autonomous sailing implies high demands on redundancy of critical systems and a high level of security (confidentiality, integrity and availability).

Besides in this level the skipper in the onshore control center should be trained to take over in these complicated situations, initial and periodical in order to maintain experience and competencies at the required high level.

Level 5. Full autonomous sailing

Conceptually this level is the ultimate autonomous fulfilment of the inland waterway system. Given the different users of waterways is not sure when and/or if this stage will be reached. In more or less closed systems (dedicated channel, dedicated types of cargo etc. ...) full autonomous sailing could be an viable option. In open systems this level requires a matureness of sensors and systems capable of detecting and predicting behaviour of for example a swimmer, kids in a small inflatable etc.

3.3 Mooring and unmooring

For mooring and unmooring of the vessels different solutions can be taken into account. If more than two crew members are still on board mooring and unmooring can be performed manually. For later stages (automation stage 4 and 5) mooring systems based on vacuum or magnetism either on board of the ship or at the shore side (port quays, waiting areas or in locks). Ship operators and terminal operators indicate that automated mooring systems can assist in a shorter turn around time of the vessel. Furthermore, automated mooring could contribute to increased safety, since mooring is considered to be (relative) hazardous maneuver.

The technology for automated mooring systems are well developed, but are currently only available at high investment costs. Furthermore, many different systems and there is no current standard. Choices need to be made, whether investments should be made on the shore side or at the vessel. For vessels that are on a long term contract sailing on a fixed route, investments of mooring at the shore are most attractive. In case the ship operates on a spot market and thus is unsure whether mooring systems are available, systems should be installed on board of the vessel.

3.4 Loading and unloading cargo

For loading and unloading of cargo different actions need to be taken into account. These actions differ between the cargo types that are being transported.

For containerized cargo, a stowage and loading and unloading plan needs to be generated. This stowage plan needs to be communicated with the terminal operator and needs to be monitored. This could be generated by an automated program that creates an optimal stowage plan and checks it against the statutory stability requirements. The activity could also be outsourced to a shore control center or an administrative back office. Monitoring of the loading and unloading plan is currently an important task for personnel on deck. This task could be outsourced to automated camera and sensor systems, to shore personnel in a shore control center or to terminal personnel.

Specifically for liquid bulk terminals, connection of hoses are currently performed manually. In an ideal end situation, the connection procedures would be performed automatically. As an intermediary step, connections could be performed by terminal personnel on the shore.

Communication needs to take place between the vessel and the terminal when to start with the transshipment process (this is currently done manually). Preferably, the terminal process should be automated so that information would be transferred directly from the automated ship/ control room to the terminal. Possible, the communication could be taken over by terminal personnel.

Ship operators furthermore consider it important to have a crew member acting as representative during the loading and unloading operation, for example to register damage or incorrect loading of the ship. In case of outsourcing to a shore support team by a terminal operator, good contractual agreements need to be made how to cope with damages.

3.5 Maintanance of the vessel

Monitoring, controlling, maintaining and repairing a ship’s machinery is an important task of the crew. A lot of maintenance and basic repairs are done by the crew during normal operations. This implies that if the crew is removed from the ship, new ways of performing these tasks need to be found. In the research on autonomous or unmanned vessels however, this aspect of ship operations has received only very little attention.

Important steps have been taken to enable remote monitoring and control of a ship’s machinery and the feasibility of this has been demonstrated on a number of vessels. Maintenance and repair of machinery and general upkeep of the ship, however, still require physical interaction of people with the ship. there are no well-thought-out solutions available for this aspect of unmanned or autonomous shipping. As a result, before such ships can sail on inland waterways, solutions need to be developed to

A) do regular maintenance on the ship and its machinery,
B) repair broken equipment that does not immediately lead to a catastrophic failure like loss of propulsion, power or maneuverability and
C) prevent or solve major/catastrophic failures that occur underway.

The first two topics can likely be solved by a combination of extensive monitoring of the equipment and a well-defined preventive maintenance concept that uses shore-based maintenance crew that performs maintenance as well as repairs while a ship is in port. This is deemed especially feasible for ships that regularly visit the same ports and spend some time there while waiting to be loaded or unloaded. This is far more common for inland ships than for seagoing ships.

This leaves the challenge of dealing with major failures while underway. In the present situation, a crew is on board that can solve problems and repair at least some broken equipment. On an unmanned ship they are no longer there, so the ship will have to cope with the problem by itself. although the solution to this problem is not trivial and requires further research, there are important aspects of inland shipping that make this challenge significantly smaller than it is for seagoing ships:

- The installations are smaller and simpler

- The engine runs on high-quality fuel (as opposed to Heavy Fuel Oil on which many seagoing ships run), making problems in the fuel supply less likely
- When ships run into trouble, a place to moor or dock the ship is usually relatively close by, so if a problem occurs a solution will only have to keep the ship operational for a limited amount of time.
- Communication with shore is much easier than at sea, facilitating remote monitoring and control that can prevent and solve problems.
- Especially the larger inland ships are twin-screw vessels. This gives them a standard built in redundancy in propulsion and maneuvering that the vast majority of seagoing cargo ships do not have.
- Many inland ships are equipped with a 4-way bow thruster that can provide emergency propulsion if necessary. This provides an additional safeguard in case of failure of the main machinery.

The maintenance and repair of ships is therefore considered a challenge, but not a showstopper for automated barging.

3.6 Administration and management

The ship administration and inventory management (such as bunkers) will shift gradually from the ship to a back office. This could be the shore control center or a dedicated administrative office.

In addition to this transfer, parts of ship administration and inventory management can be automated by systems. Data required by infrastructure managers could for instance be generated automatically from the cargo plan and the ship management plan can be generated automatically by the ships maintenance sensors. This would require that data on board the vessel is available for different purposes and that data sharing between the vessel and other involved stakeholders becomes available.

4 Important preconditions for autonomous sailing

4.1 Legislation

4.1.1 Introduction

The implementation of autonomous sailing can lead to a reduction of the number of personnel on board of inland vessels. An important precondition is that the current legislation on minimum crew requirements set up in the Regulations for Rhine navigation personnel are adopted. This paragraph describes how legislator can adapt the existing system for manning regulations in order to accommodate technological changes. For this legislative analysis, additional consultation interviews have been performed with different government agencies, classification bureaus and legal experts from the industry representatives. Stakeholders in inland shipping indicate that the current crew regulations are outdated and need to change into a more adaptable system that takes into account different investment. This section will present a framework based on the safe manning principle that can be used as a base for changes in regulations.

4.1.2 Principles of minimum safe manning

In maritime shipping, the minimum crew requirements are determined at the level of the individual ship. The so-called "Principles of minimum safe manning" system came into effect when the IMO assembly adopted Resolution A.890 (21) in November 1999. In previous regulations concerning manning regulations in maritime shipping, the regulator strictly stipulated the number of crew members required per ship type as well as the required certificates. The principle of minimum safe manning requires the ship owner to design a minimum crew plan, taking into account the type of ship, the sailing area, the type of cargo and the degree of automation. The crew plan describes which crew members perform which tasks and how the ship can operate safely even in emergency situations. The crew plan is submitted to the flag State or a classification agency for approval. When approved, the ship is awarded with a minimum crew certificate.

A similar system for determining the minimum crew requirements could be a suitable system for inland shipping. The main advantage of applying this system is that it gives room for technological developments such as autonomous shipping, it is a more dynamic legislative framework. In addition, the system encourages the ship owner to invest in innovations to make operational management more efficient and, if possible, to reduce the number of crew members where this is possible safely.

4.1.3 Tool for determining the minimum manning requirements

An important part of new legislation would be determining what the safe minimum required crew is on board a vessel. Preferably, this is determined in a standardized framework, in order to keep the implementation costs low. Together with the Dutch Navy, TNO has designed a digital tool that can link the work (or task onboard) and workforce (crew) for a specific vessel. The Crew Design Tool (or CDT) assists shipowners in determining the optimal crew size and crew mix as well as the level of automation. By using CDT, it is possible to accurately determine the number of crew members needed to operate the ship in different operating situations (ship modes) and to calculate the personnel costs (representing a large proportion of the operational costs) before making new investments on a ship. By using the CDT it can also be determined whether it is interesting to automate work (machine workforce) in relation to the manual execution of the work (personnel workforce). For this research some adjustments to the program have been made to accommodate inland waterway vessels.

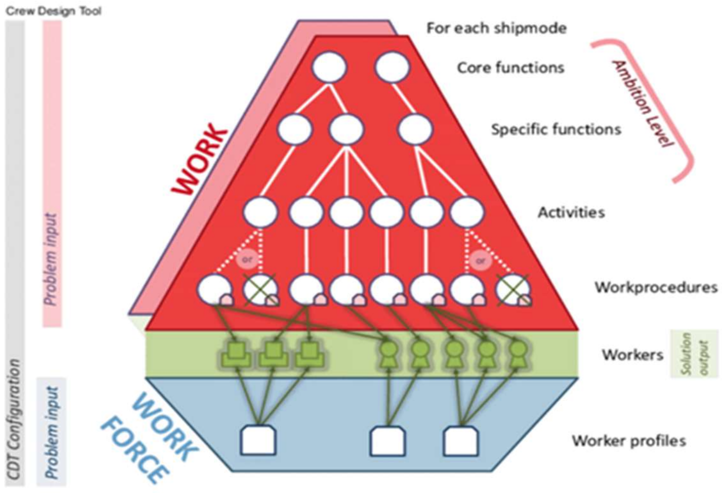
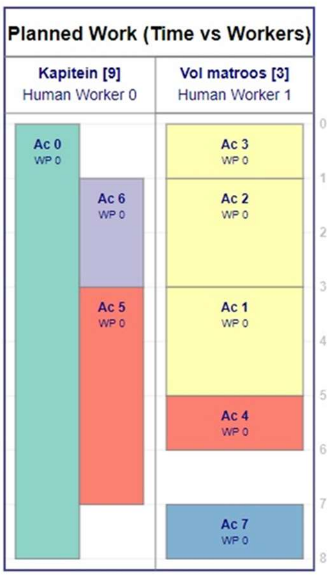


Figure 8: Crew Design Tool

The crew design tool uses the filled in operating mode of the vessel to determine the activities needed to operate the vessel (work). These tasks can be linked to both available workers (personnel workforce) or to automated systems (machine workforce). Every worker, both human and machine, has a profile that consists of: education level, disciplines and the number of hours that are available to work per unit time. The CDT then makes the most optimal planning for carrying out the work with the available workers and determines the total costs of the current configuration. With the tool, different scenarios (for instance with different levels of autonomous shipping) can be calculated.

The figure below shows an example of output of the tool. The figure left shows an optimized planning for a vessel with 2 crew members (small vessel sailing at daytime operating mode). The planning shows different activities (AC) that are subdivided by different workers. As shown, a worker can sometimes perform several tasks simultaneously, depending on the occupancy rate of the tasks to be performed. The figure on the right shows the same vessel and operating profile, but with a different scenario. In this scenario, several tasks are performed by automated systems or by a back office, resulting in a reduced crew size.



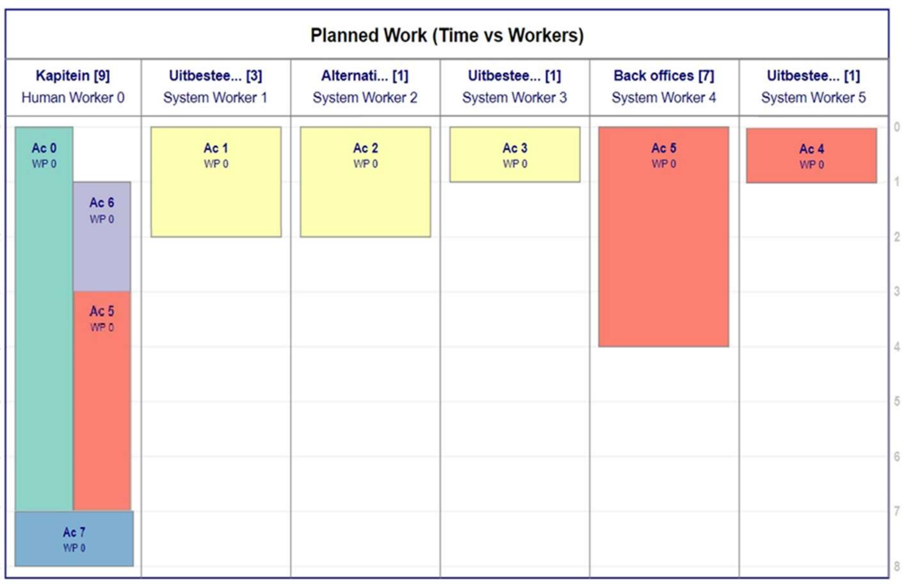


Figure 9: Example output for a day time operated vessel in two scenarios

Application of tools, such as the crew design tool, could serve as a standard method to determine the minimum crew strength. As a result, the entrepreneurs are guided in writing the crew plan and the chance of approval is greater because the results are based on an approved method.

4.2 Communication

Digitalization for the inland shipping sector can potentially help to improve its competitiveness in an environment in which other transport modalities are (also) developing rapidly towards higher levels of efficiency through new digitalization and information sharing technologies. The evolution towards autonomous inland shipping is a potential area to not only improve competitiveness and efficiency, but also safety in navigation.

The required information and communication technology for enabling autonomous inland shipping is rapidly becoming mature and available. Nevertheless, the evolutionary path towards autonomous inland shipping will be gradual, in which it will take still time and numerous hurdles to be taken before truly 'autonomous' inland shipping for the majority of inlands ships will have become reality. A 'big bang' towards autonomous inland shipping is unrealistic.

The gradual evolution towards autonomous inland shipping requires timely acting on the anticipated required changes in both on-board and shore information and communication technology. Hence, the subsequent paragraphs in this section elaborate the main aspects of digitalization for inland autonomous shipping:

- the stakeholder ecosystem,
- the information sharing architecture,
- the communication requirements, and
- the security prerequisites.

Addressing these aspects will pave the way for a roadmap of intermediate levels of automation- towards inland autonomous shipping, with an ever lower degree of monitoring and intervening responsibilities by the ship's crew members.

4.2.1 The stakeholder ecosystem

Many stakeholders are involved in the exchange of (digital) information and communication for the various processes for inland shipping and logistics. With the advancement of autonomous shipping and the need for information sharing, this will only increase even further. To be able to handle the increasing complexity of the information sharing and communication requirements, a well-structured and optimized technical IT- and communication infrastructure is needed, designed and described in the information sharing architecture. Its basis is formed by the 'chain 'of various stakeholders in the digital information exchange processes for inland shipping, i.e. the '*digital inland shipping ecosystem*'.

Multiple variants of the digital inland shipping ecosystem may occur, varying in the level in which they use a centralized information sharing role. Figure 10 illustrates two variants that represent the opposite ends of the spectrum:

- A ‘bilateral’ variant reflecting a distributed digital inland shipping ecosystem with direct bilateral information sharing and communication relations between the ship and the other stakeholders.
- A ‘centralized’ variant with a pivotal coordinating role in the information sharing processes between the various stakeholders. Centralized variants are currently gaining attention for managing the Business-to-Business logistics information sharing processes, with barge operators may fulfill this role by means of a ‘control tower’. For the navigation processes, the centralized variants are an option in the evolutionary roadmap towards truly autonomous inland shipping with (multiple) ships remotely monitored and controlled from a control tower.

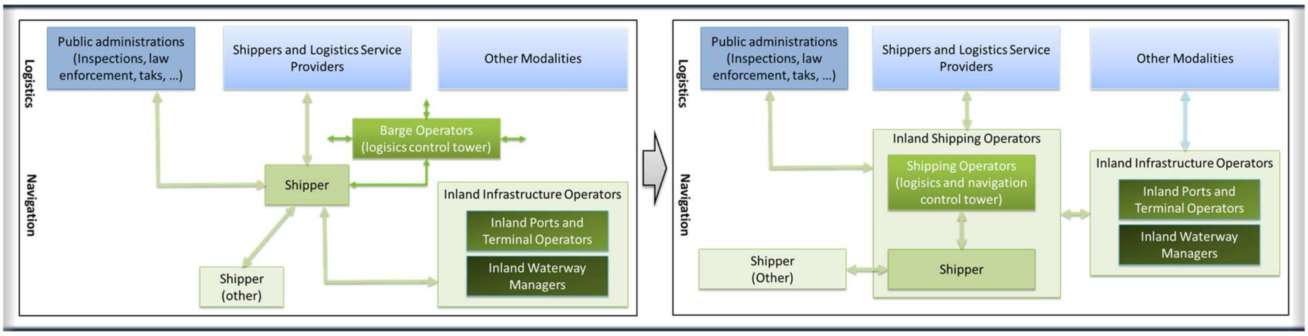


Figure 10: Evolution of the Digital inland shipping ecosystem.

Multiple intermediate variants of the digital inland shipping ecosystem are likely to co-exist simultaneously, with various appearances depending on the specific business models of the shippers and the barge operators. This requests for flexibility in the information sharing architecture to enable a variety in digital inland shipping ecosystem. This will be considered in the following paragraph.

4.2.2 The information sharing architecture

A well-designed and flexible on-board and on-shore information sharing infrastructure is key in the (gradual) evolution towards autonomous inland shipping. As reliable communication channels with abundant bandwidth cannot and should not be taken for granted, neither can be the capability to remotely control the ship. Hence, a robust on-board information sharing and processing infrastructure to support on-board (and on-shore) monitoring, control and decision making capabilities is a basic necessity in which the ship itself forms a pivotal point of designing the reliable information sharing and ICT infrastructure.

To support the various levels of autonomy for inland shipping, the right data for decision making and the proper interfaces for controlling the ship and its systems must be available, both on-board and on-shore. This not only applies to the data and interfaces required for (autonomous) navigation but also for the data and interfaces for:

- the ship’s technical systems, e.g. the propulsion (engine related), and
- the process monitoring systems, including the cargo (e.g. stability plan) and arrangements with terminals or other shippers.

The on-board and on-shore availability of these required data sets and interfaces for the monitoring, control and decision making processes for autonomous shipping form the basic support infrastructure paving the road for the evolution towards inlands autonomous shipping.

Figure 11 illustrates a ICT infrastructure for autonomous shipping. It has been derived from the proposed architecture for autonomous maritime shipping in the EU MUNIN project, but updated to reflect the case of autonomous inland shipping.

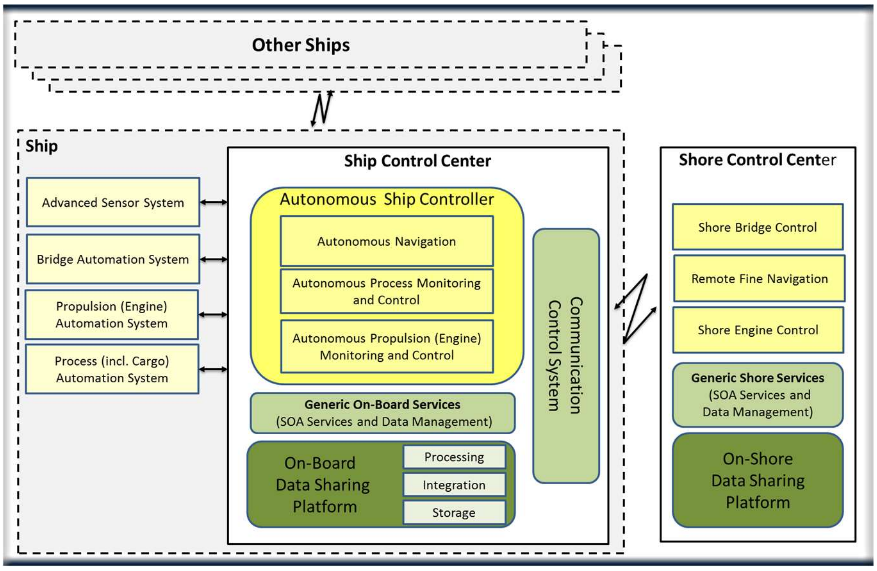


Figure 11: High-level information sharing and ICT infrastructure for inland autonomous shipping.

The high-level information sharing and ICT infrastructure for autonomous shipping as illustrated in the figure adheres to a set of design guidelines. These design guidelines are enumerated in Table 1

The information sharing architecture	
1	• Enable sharing of data between the main functional groups: propulsion (engine related), navigation, communication, and process monitoring (including cargo and logistics): – Make all relevant data available across the main functional groups to enable integral monitoring and decision making, both on-board and on-shore. – Prevent 'data silos', even though this may not always be in the (commercial) interest of system suppliers
2	• Adopt a structured data model for interconnecting and interoperability of the various information systems required for inland autonomous shipping: – Aiming at a data model for completeness and operational efficiency – Based on the decomposition in the main functional groups as stated in (1) – Use well-defined, open and (preferably unique) standardized data models.
The ICT architecture	
3	• Enable multiple variants of the digital inland shipping ecosystem – Support a flexible on-ship and on-shore ICT-infrastructure in which multiple variants of the digital inland shipping ecosystem can be supported (and migrations between them) without requiring (expensive) changes in the ICT-infrastructure.
4	• Use a modular architecture with clear boundaries between function (sub) systems: – Create a 'separate' data infrastructure to enable processing functions across the main functional groups as stated in (2), both on-board and on-shore.

	– Apply well-defined, open and standardized interfaces – Create a portfolio of generic, re-usable and reliable services (e.g. for location, speed, direction, temperature) to prevent duplication and inconsistencies between data sources ▪ E.g. by means of a Service Oriented Architecture (SOA) module	
5	• Implement a highly reliable ICT and data sharing infrastructure: – Supporting both real-time decision making and historic analysis and auditability – With build-in failure protection mechanisms	

Table 1: Design guidelines for the information and ICT architecture for autonomous inland shipping.

4.2.3 Communication requirements

Always-available and high-bandwidth communication channels between ship and shore can and should not be relied upon in the roadmap towards autonomous inland shipping. Hence, the information sharing and ICT infrastructure has to be designed for resilience against unavailability of the communication channels between the inland ships and the shore, as described in the previous paragraph.

Nevertheless, a highly reliable and available communication network infrastructure is a key requirement for (many of) the new digital solutions underlying the digitalization of inland shipping and boosting the viability for autonomous inland shipping in the various levels of its evolutionary roadmap.

Hence, a reliable and highly available communication network infrastructure is needed, featuring:

- ubiquitous availability,
- sufficient bandwidth,
- adequate data quality parameters with respect to data loss and delays.

For inland shipping, various types of communication network infrastructures are available: Radio, Wireless Mobile, WiFi, Satellite, LoRa . For reduction of complexity (and therefore also minimizing the chances of incidents) it may be advantageous to agree upon the same type of com communication network infrastructures to be used where possible. The combination of Radio and Wireless Mobile (4G, 5G) seems to be an obvious choice. Ubiquitous availability and bandwidth of these communication network infrastructures should be aimed at.

In the high-level information sharing and ICT infrastructure for autonomous shipping as shown in Figure 11 a communication controller is foreseen as a module to manage and control the available communication channels separate from the information sharing and processing modules.

4.2.4 Security as prerequisite

The digitalization of inland shipping creates many opportunities, but also exposes the inland shipping sector to a new category of threats. There have already been examples in real life where actors in the sector have become victims of cyberattacks.

As the degree of digitalization increases, these kinds of attacks will become more frequent and the case of autonomous shipping may carry more severe consequences of security incidents unless proper controls are put into place. For example, if the control commands from a shore control tower to a remote controlled ship are disrupted or spoofed by a malicious actor, then this could lead to collisions damaging ships and shore-based infrastructure, and even causing personal injury. Similarly, a well-timed denial-of-service attack targeting remote-controlled ships in an important port area can effectively cause a blockade. In the case of autonomous ships, disrupting sensors or spoofing AIS and GPS data could result in collisions due to incorrect situational awareness. Evidently, one of the key requirements on the communication and IT infrastructure, both in the shore control tower and on remote controlled or autonomous ships, is that it is secured against these cyber-physical threats.

While it is technically feasible to design the on-shore and onboard IT infrastructure and communication protocols in a secure way, for the entire system to *remain* secure, proper cybersecurity practices will need to be followed by the operators. It is necessary for the inland shipping sector to see robust cybersecurity not as an afterthought or additional expense, but as one of the core principles enabling remote controlled and autonomous shipping, following proper network security practices such as running the ship-shore communications through (virtual) private networks, securing the communication infrastructure with firewalls and gateways, and monitoring, analyzing and shaping network traffic to and from the shore control tower to detect and prevent intrusions.

Keeping IT systems on-shore and onboard updated to mitigate new threats and vulnerabilities as they arise should be considered as important as the physical maintenance of the ships themselves. Robust cybersecurity design processes are key, in which a proper balance is established between security threats, their impact if they occur and the (costs of) mitigating measures. Doing (and regularly updating) a Risk Assessment provides the means to do so.

4.2.5 Recommendation

Many of the developments in the information sharing and ICT-infrastructure for inland autonomous shipping as described in this section are the responsibility of private actors. Nevertheless, it is possible to stimulate its development by specifying the shared (and public) requirements to these infrastructures, including:

- an overall (governance and architectural) framework for the information infrastructure for inland autonomous shipping,
- standards for data models and interfaces to be developed,
- the availability of adequate communication network infrastructures,

Currently, the European Commission is exploring the requirements and solutions for the digitalization of inland shipping, with the focus on logistic processes. As such, a Digital Inland Waterway Area (DINA) is being developed intending to interconnect information, infrastructures, people, operations, fleet and cargo in the inland waterway transport sector.

Inland autonomous shipping is an additional important development that could and should be considered as one of the drivers for the (architecture underlying) future digitalization initiatives for inland shipping.

It is proposed to develop a field-lab for the information sharing and communication infrastructure required for inland autonomous shipping to further elaborate the high-level architectures and approach as presented in this section, to demonstrate their viability and to stimulate further development of standards on data models and interfaces. A broad consortium (under auspices of the top-sector) consisting of partners from the inland shipping sector, solution providers and knowledge institutes could be brought together in a project pursuing these goals.

4.3 Investments in shore activities

4.3.1 Shore control center

An important shore side investment is the development of a shore control center which takes over important task on board the vessel such as remote navigation and monitoring of the vessel, communication with other vessels and supply chain stakeholders and performing other backoffice functions. Shore activities could be performed at different locations (e.g. navigation at one location and monitoring of the engine systems at another).

A key issue in development of the shore control center is how shore-based personnel receives appropriate information and is able to give commands to the ship in all circumstances. Besides requirements for the communication infrastructure of an autonomous shipping, design of the shore control center to ensure a good situational awareness for shore personnel is imperative. Situation awareness of involved personnel generally decreases as the level of autonomy increases. An analysis of incidents between humans and automated systems shows that common causes are around misunderstandings, over-reliance and feedback provided by system states. How to organize remote human-system interaction or system-system is an important research question because the assumption that autonomous systems will always react in an optimal way to its environment is a simplification.

Technical development and gaining practical experience with remote control of ships is an important development area for the coming years. Most likely, shore control centers will not be exclusively developed for inland shipping alone, but will involve maritime shipping as well.

4.3.2 Investments in quay facilities and port services

Terminal operators, infrastructure managers and port authorities need to investigate what impact remote controlled and unmanned ships have on their day-to-day operations. A first important aspect is mooring facilities, either by facilitating mooring equipment on board of the vessel, or to invest themselves in mooring equipment at the quay. Operators indicate that they see advantages in automated mooring both in the field of safety (they consider to be a relative hazardous operation) and in turnaround time.

Requirements in communication may lead to additional investments for shore side parties. Improved data sharing between the inland ships and the operators and infrastructure managers could lead to better real time communication between the different stakeholders. Terminal operators in sea ports indicate that they could benefit from this by better aligning the inland vessel to the maritime vessels, to lower the dwell time of cargo at the port facilities. Furthermore, quay personnel can be planned better, especially when maritime vessels are also included.

Port services, such as bunkering and piloting (in case of maritime shipping) also need to investigate how to best accommodate remote controlled and unmanned vessels.

4.4 Education

4.4.1 Changes in the required tasks

The implementation of autonomous shipping is expected to have a large impact on the activities performed on board inland vessels or at shore locations. This will have impact on both the requirements of new personnel and on education.

In the first phases of autonomous shipping, tasks performed onboard will not change dramatically, since the sensor systems placed on board are only supporting. Education of personnel therefore needs to be focused on all current tasks performed onboard. In the longer term, it is expected that tasks on board is performed by a mix of personnel and autonomous systems. This requires additional skills of personnel such as electrical engineering, knowledge of automated and autonomous systems and information and communication technology (ICT). Many inland waterway education institutes are developing new courses to teach students to develop themselves and to deal with new systems such as autonomous systems. Because personnel will often act as a fall back option for automated systems, it is imperative that they are also still knowledgeable on all current activities on board the vessel, such as monitoring and navigation of the vessel and performing emergency repairs.

4.4.2 Changes in education programs

The consequence of ships becoming more autonomous and thus requiring less crew members is that there are will be fewer internship places and thus fewer opportunities to learn the profession in practice. In order to gain practical experience this role needs to be taken over either by internship opportunities at shore control centers or by using simulator training. During simulator training the student can be taught to sail with different types of inland vessels in all kinds of situations, but the simulator also offers possibilities to train the students and crew of (semi) autonomous ships to quickly create a situation awareness and to be able to intervene when the autonomous system no longer functions properly. The Dutch education institutes already have various simulator facilities that enable to train the crew now and in the future.

Changes in inland shipping courses due to application of autonomous shipping need to be implemented at a European level, to ensure that all personnel throughout Europe is qualified in the same way. Changes therefore need to be discussed and ratified in the “Education in Inland Navigation” (EDINNA) network.

5 Roadmap: how to develop automated barging by 2025

5.1 The timeline and development stages of automated barging

As shown in the previous chapter, some major developments need to take place for development of autonomous shipping. This section provides a possible roadmap.

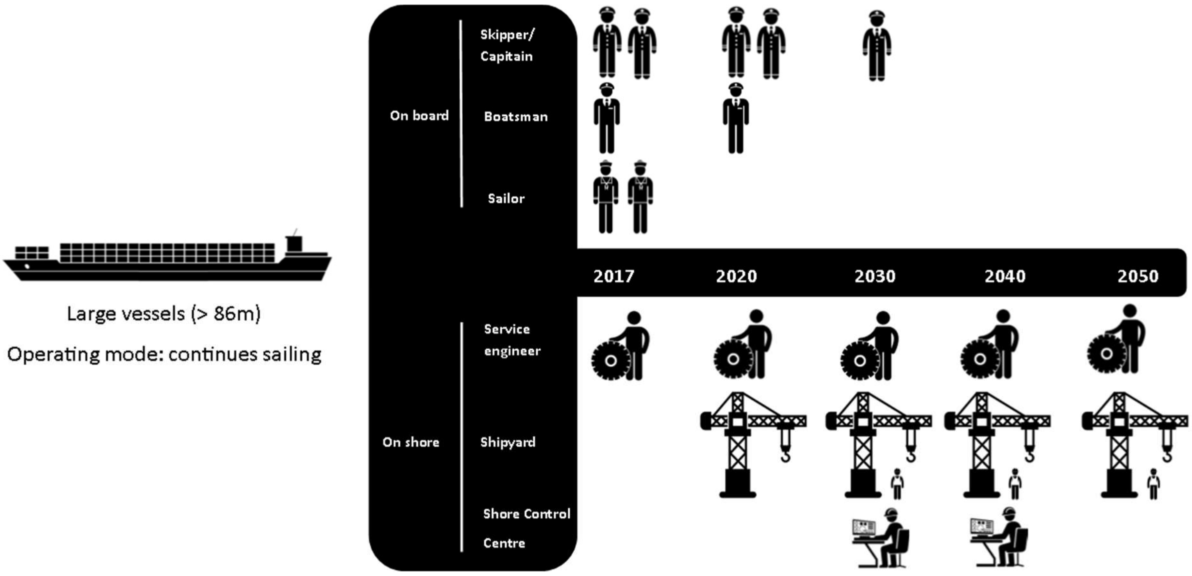


Figure 12: Roadmap for autonomous shipping

Sensor supported vessels

In the first stage sensor systems will be installed onboard of the vessel that support the crew members (stage 2 of autonomous sailing). Navigation of the vessel will be operated by the captain or skipper at all times, but support will be provided by implementation of a track control system. At this stage, tests need to be performed on the reliability and accuracy of the systems under different real-life conditions. By applying these systems in practice, mathematical models can be developed and verified for vessel dynamics, condition and health monitoring.
Engine and ship maintenance sensor systems can support the day-to-day monitoring of the vessel. Based on the extensive monitoring, maintenance tasks can be must be partly outsourced to a shore organization. In addition, the ship administration can be moved to the back offices and the making of the stowage plan and stability calculation can be simplified by a program that automatically performs this. As a result, the work pressure for staff on board the vessel will become lower and it would be possible to sail with fewer crew members for full continuous vessels, or to sail for more hours for a ship that currently.

At the start of this phase, pilot projects need to be performed in order to do so safely. Based on the pace of changes in regulations, these pilot projects can be gradually implemented in a larger share of inland shipping.

Semi-autonomous or remote controlled vessel

In a semi-autonomous vessel, the ship sails independently during parts of the route, supported by a shore support center. There is still crew on board to navigate the vessel in the port area or in case of difficult maneuvers and to help with mooring and unmooring procedures. During the autonomous sailing of the inland vessel, a shore control center will supervise safe navigation. This allows the skipper or captain to rest.

To realize semi-autonomous navigation, the navigation systems such as autopilot, the electronic chart, depth sounder, Automatic Identification System (AIS), Radio Detection and Ranging (RADAR) and other detection systems must be integrated. In addition, the autonomous inland vessels will have to be able to communicate with autonomous and non-autonomous vessels and with other stakeholders, such as infrastructure managers, port authorities, shippers and terminal operators. To support the necessary data transmission and the communication, a reliable open data platform is required.

Work performed during loading and unloading of the vessel may partly need to be outsourced to shore personnel of the shipper or terminal operator. This would require new contractual agreements.

Unmanned sailing

In a fully autonomous vessel, no crew on board would be required. For new build vessels, this leads a significant cost reductions. Significant design changes on the vessel include discarding the deckhouse and hotel systems. Especially in smaller canals this could lead to a significant improvement of the cargo capacity. Although the ship is operating autonomously, support functions will be performed from the shore control center. This could be navigation support, but also overall management and administrative support.

n order to realize fully autonomous sailing, the technique and applied systems used in semi-autonomous sailing must be further developed so that the systems can handle complex situations such as in the port area. Furthermore, investments need to be made for autonomous mooring and unmooring and automated cargo handling. The first application of unmanned sailing will probably be vessels operating on a fixed route on a relative short distance. In these cases, the initial investment costs for the stakeholders involved will be relatively low.

5.2 Stakeholders

In the development of autonomous shipping different stakeholders are involved.

1. Given the function of the vessels (with the focus on transport of cargo) it concerns the organizations in the transport chain. Shippers of cargo, transport service providers, ship operators, ship owners and crew.
2. From the viewpoint of planning of and using the waterway infrastructure: authorities and regulators (national, EU-regional and on a European level) , vessel traffic management, lock and bridge operators, RIS service providers, ports/terminals
3. Related to the former stakeholders: other users of the waterway and the people in communities near the waterways. To what extend is autonomous sailing perceived as a threat with respect to safety? Good communication and explanation is required already starting as soon as pilots are prepared.

4. And last but not least the technology developers related to ship design and construction, infrastructure and harbor/terminal equipment, ICT and ICT security developer and service providers.

Given these different stakeholders standardization, interfacing and redundancy and security are important aspects.

5.2.1 Stakeholders in the transport chain

Shippers of cargo

The main concern of shippers of cargo is the delivery of their products on time, at a certain cost level and a low (zero) emission level is gaining importance. A certain quality level in handling their goods is a basic requirement (no damages etc.). The (autonomous) ship is a mean of transport, and it has to perform on the required service level. Automation and an increasing level of autonomy has to contribute on maintaining and improving the service - and cost levels.

From the viewpoint of reputation it could be of interest for some companies to contribute and/or participate in autonomous shipping.

The transport and logistics service providers

The transport and logistics service providers also use ships as a mean of transport: costs, environmental aspects and quality count. For them the information exchange with the ship operator is also an important aspect. Being able to preparing load plans in advance, actual information on the position and status of the cargo and the ship are a “must have” in transport chains.

Ship operators, ship owners, crew members

Autonomous shipping provides opportunities and threats for ship operators and ship owners. A higher level of automation could solve manning problems in combination with a lower level of operational costs. It is not yet clear at what point in time (in the future) these benefits are larger compared to the extra costs of automation. The business case aspects of autonomous shipping determine the viability of the different phases in the development.

The ship owners involved in the study supported further automation in order to reduce the number of crew. The main bottleneck in this respect are the manning regulations and the flexibility of the authorities to grant a (temporary) permit during pilots/first steps.

The challenges for crew members are twofold; automation means less jobs, at the other hand as long as personnel aboard is required the job will become broader and ask for more skills and competencies.

5.2.2 Waterway infrastructure stakeholders

Planning, realizing, maintaining and operating waterway infrastructure will be affected by autonomous shipping. Without a parallel development in infrastructure real autonomous shipping is not possible. The existing systems and organizations on vessel traffic services, river information services need to anticipate and prepare. Autonomous ships impacts the passing of locks and bridges: solutions are needed for waiting/mooring before the bridge/lock, mooring in the lock, etc.

Terminals and ports have to consider solutions for automated mooring and further automation in cargo handling for inlands ships. Which migration scenarios are viable form a business perspective. How to secure safety, physical and with respect to ICT and cyber security.

Policy makers and authorities need to anticipate with respect to maintenance an renewal of infrastructure, vessel traffic management and river information systems.

Timely adapting rules and regulations in order to cope with the migration to autonomous shipping is recognized as a major challenge to cope with by CCNR and the CESNI ("Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure" – CESNI, the EU committee for drawing up common standards in the field of inland navigation).

5.2.3 Nonprofessional users of the waterways

Recreational users of the waterway and the people living in communities near the waterways will monitor the developments of autonomous shipping. From their perspective it is essential that they have trust in the safety of autonomous shipping. Identification of these stakeholders in combination with communication, explanation and involvement is required from the start of concrete initiatives/pilots. Stakeholder organizations, such as HISWA, and representatives of municipalities should be involved at an early stage.

5.2.4 Technology developers

Autonomous shipping will be enabled by equipment and automation with respect to

a. The ships (and the cargo) and the ship operator
   Developers and suppliers of navigational equipment, accurate electronic charts, sensors for detecting other vessels/objects. Automation of tasks aboard with respect to maintenance and operation.
   The development of control rooms on shore.
b. Terminals/quays
   Further automation of cargo handling, interchange of information with the ships involved, automated mooring.
c. Vessel traffic services/RIS
   These systems need to anticipate on how to deal with the migration: combinations of ships that are manned, partly automated and fully autonomous. What are the different levels of autonomy to deal with in the future and per stage.
d. Equipment/systems for ship handling in case of bridge passages, lock passages and mooring in case of waiting and in a lock.

There will be a need for communication platforms/standards to enable the information exchange between the different systems/organizations involved.