The automated and unmanned inland vessel

E. Verberght, University of Antwerp and E. van Hassel
University of Antwerp, Prinsstraat 13, 2000 Antwerp, Belgium

edwin.verberght@uantwerp.be; edwin.vanhassel@uantwerp.be

Abstract. Automation is an ongoing development that has already changed the inland waterway transport sector (IWT) fundamentally. One of the next possible steps is the technology for fully automated operation systems under conditions and with the possibility for human intervention from on-shore. This article develops and explores a fully automated and unmanned inland vessel and questions if a positive business case for the IWT and society is possible. It also identifies the success and failure factors of this innovation. Two analyses were applied regarding barriers that could prevent market uptake (System of innovation approach, SIA), and the social costs and benefits of automation (Social Cost/Benefit Analysis, SCBA). The innovation has the potential to be disruptive in the entire supply chain as all transport modes are discovering their automation potential. The technology is assumed to have a possible impact on vessel safety, trip planning, fuel efficiency and even freight capacity. Also the institutional framework of the European IWT is taken in account regarding crew requirements and safety standards.

1. Introduction

Automation is finding its way in our daily life and certainly in our ways of transport. These kind of innovations have the possibility to radically alter our movements. Developments can be witnessed in all modes of transport. In order to stay competitive towards other modes, innovation in inland navigation is crucial. To answer the question if the innovation offers a positive business case for private investors and has social benefits, a social cost-benefit analysis (SCBA) is applied. Secondly, the systems of innovation approach (SIA) allows to identify success and failure factors of the innovation and also gives an actual overview of the current development phase. This article is one of the results of more elaborated research that led to the INN-IN report [1]. But first of all, automation in inland navigation still needs a definition which is here elaborated from a literature review and several expert interviews.

2. Literature review

Today there is a global contamination in definitions with inconsistent and interchangeable usage of the words ‘autonomous’ and ‘automated’. Several definitions are possible to define autonomous an fully-automated vessels. Most of them originate from robotics literature and are here rephrased to fit inland vessels. In this paper ‘autonomous’ is considered as a vessel that is able to decide for itself without human intervention while ‘automation’ still requires human decision making or monitoring and intervention. Several authors have defined automation and autonomous according different stages of development with autonomous being the final stage. Autonomous suggests here a developed form of artificial intelligence, while automation still needs human monitoring to solve extraordinary events where programming is perhaps not adequate and where the human creativity is still far more superior than any AI that is developed so far.
Not much literature is found for inland navigation specifically. In other modes a global industry is emerging, led by companies such as Google for road haulage of freight and passengers, Rolls-Royce for maritime ocean liners, and several others. This inspired a number of researchers [2] and research projects (MUNIN project, AAWA and Yara Birkeland [3]). To define ‘autonomous’ Alami et al. [4], stresses the ability of the machine, robot or in this case vessel, to carry out actions and to refine or modify the task and its own behaviour according to the current goal and execution context of its task. The autonomy should be in this case aware about its behaviour and adjust to the execution context of its task for what it is created to perform. Bekey, Wooldridge & Jennings and Huang [5] describe autonomy as a system that should be capable to respond without human intervention for extended periods of time (Bekey) while complying to the condition or quality of being self-governing (Huang) and having some kind of control over its actions and internal states (Wooldridge & Jennings). Frequently used definitions are derived from the levels of autonomy as described by Sheridan [6] which is a 10-point scale categorizing higher levels of automation as representing increased autonomy, and lower levels as decreased autonomy [7]. According to Van Den Boogaard et al. [8], the suggested stages of autonomy do not work in one direction. Because of safety uncertainties, especially in the initial phase, it is necessary that the system must be capable of operating in multiple levels without reducing the overall safety performance. Also, if remote control fails, an unmanned ship needs reliable emergency procedures to dock automatically and in a safe way. At that moment of system failure the ship needs to be fully automated or even autonomous, if necessary with backup systems. Another relevant study is the Finnish Advanced Autonomous Waterborne Applications Initiative (AAWA) in collaboration with Rolls-Royce, which brought together universities, ship designers, equipment manufacturers and classification societies to explore economic, legal, social, regulatory and technological factors. This review leads to the following definition for automation: the process of a growing variety of organizational, operational, and/or technological innovation initiatives, that is aimed to increase support or even to replace human tasks by a device, (or machinery) or an integrated system that in the end will be able to conduct all human tasks (continuously and unconditionally) and is programmed to accomplish (partially or fully) a growing number of functions that were previously, or conceivably could be, only carried out (partially or fully) by a human.

3. Defining the automated and unmanned inland vessel

The fully automated and unmanned inland vessel (AV) has a completely automated operating system (AOS) which performs all tasks on board such as navigation and propulsion. The AOS integrates all scanners, devices, the automated engine room, automated docking stations (such as developed by Cavotec or Trelleborg), the automated helmsman, the on-board bunkering system [9], automated cargo management system [10], and maintains communication with the shore control centre (SCC), locks, bridges, ports, terminals, other ships and authorities. The AOS allows on-board and on-shore inspectors to communicate with the ships system. The SCC monitors one or more vessels, only intervenes when necessary, and makes decisions that are not programmed in the AOS. The SCC can be public or private and employs captains and engineers on-shore. The Human-Machine-Interface, the workload, situation awareness, liability, data size, connection reliability and security, quality of data, connection speed and even the design of the SCC are just a few of the remaining challenges that invite further research. The AV is active in normal navigational circumstances while passing locks and bridges. It can sail on its own, in convoy or in platoon. It also connects with the existing digital infrastructure for data transmission (inland river information service infrastructure). The existing digital infrastructure with notices to skippers, inland automated identification system, electronic navigational charts, electronic reporting, could need an upgrade to allow automated vessels but this lays outside this research. The AV has to retrieve vital information and adjust its course to maintain the required safety level. The vessel integrates a redundancy of automated subsystems and components that aim at replacing human tasks. Most systems that are required by an AV, are still in development. Every component is assumed to have sufficient inter-compatibility to provide a smooth integrated Automated Operation System (AOS) of all automated subsystems and robotic devices on the fully
automated vessel (AV) that can sail unmanned but still needs human decisions. A conventional propulsion is chosen, which makes it relatively easier to compare with a conventional vessel (CV). To facilitate and truly automate the bunkering system, it could be easier to choose for electrical batteries for the AV, but this is another innovation and is kept outside the analysis. Only a few described systems are already on the market and are monetarized in this article: the annual cost of the SCC service, the AOS and automated docking systems. The automate bunkering, solutions for the engine room and the automated cargo system are not included. The latter tasks are assumed to be performed or organised by human intervention. A charter rate of 1% provision is assumed and is tested during the sensitivity analysis with an assumed 7% provision. In this ex ante research, the vessel is assumed to navigate without helmsman and can perform mooring operations without human intervention. As said, an external shore control centre supervises the vessel and also organises the maintenance and repair. The latter is of course an assumption and can be completely different in reality as the innovation is still in the initiation phase.

4. Applied Methodology
The modelled vessel is subjected to an SCBA and a SIA. The SCBA identifies the costs and benefits of the innovation, calculates the net present value of different scenarios and answers the question if the innovation is positive for society and for private investors. The SIA identifies failure and success factors during different stages of innovation development and link these with the responsible actors within the innovation network. The combination of both analyses gives a deeper understanding of the current status of the automated inland vessel and the challenges that the innovation still faces. The literature review in this article did not focus on the used methodology. SIA is more explained in Vanelslander et.al. [11] and Aronietis [12]. A more detailed literature review concerning SCBA together with a elaborated application can be found in van Hassel [13].

5. Cost-Benefit Analysis
The costs and benefits are viewed from the perspective of a vessel owner and society. A conventional vessel (CV) with four crew members (baseline-scenario), is compared with a fully automated vessel (AV) in different scenarios. The following benefits are identified: Increased safety by removing the human error [14]; Higher efficiency of cargo space utilisation and less crew cost; Less fuel cost and lower emissions. Looking at the costs, the most outspoken and expected cost change is the crew cost (EUR 272,800 on the CV). Following costs are also identified: SCC service [15] is assumed to cost annually EUR 190,960; the capital value of the CV is assumed to be EUR 2,000,000 and the AV is EUR 5,900,000 [16]. All further identified costs in the initial year are show by Table 1.

|                          | CV     | AV     |
|--------------------------|--------|--------|
| Capital value            | 2,000,000 | 5,900,000 |
| Lifespan vessel          | 40 years |        |
| Leverage (70% of capital value) | 1,400,000 | 4,130,000 |
| Payback period           | 15 years |        |
| Number of crew (persons) | 4       | 0      |
| Maximal loading (tons)   | 3,000   | 3,300  |
| Terminal value (scrap value) | 80,000    |         |
| Maintenance & Repair     | 50,000  | 26,586 |
| Insurance                | 28,000  | 67,850 |
| Salaries (gross)         | 272,900 | 0      |
| Technical compliance (certificates) | 9,000   | 6,750  |
| Administration & communication | 3,000 | 300    |
| Financial cost           | 130,359 | 384,560 |
| SCC service              | 0       | 190,960 |
| Charterers provisions    | 67,760  | 10,861 |
| Fairway & port dues      | 15,154  | 19,002 |
| Fuel costs               | 164,316 | 134,082 |
| **Total cost**           | **740,389** | **840,951** |
| **Revenue**              | **968,000** | **1,086,096** |
For the first year, the conventional vessel has an estimated revenue of EUR 968,000 based on the following assumptions: A fixed freight rate of EUR 2.15 per tons within a long-term fixed contract; Three trips per week are fully loaded (no empty sailing); Freight rate is negotiated under a long term fixed contract; Every trip takes ten hours on average; Maximum payload is 3,000 tons for the CV. The AV has more cargo and trips than the CV (time benefit and more cargo space, as explained further) During the lifespan demand of the AV and CV, the IWT sector is assumed to grow as such that freight rates stay stable. In a more complex approach, own-price and cross-price elasticity of demand would lead to more volatility of the freight rate as Beuthe et al. describe [17] but this is not included in the analysis. The Lifespan of both vessels is estimated at 40 years, which is not uncommon in the European IWT. The design life of the docking stations is according to the manufacturer 20 years. The AOS hardware (including subsystems) has to be replaced during the lifespan of the vessel. The payback time of the loan is 15 years. The residual value (after the end of the lifespan) of the vessel is estimated at EUR 80,000 as scrap value, according to prices of the initial year of investment. For the automation systems, the residual value is estimated to be zero and the rest of the vessel has the same value as the CV. In reality, the residual value depends on the scrapping or second hand market price. But for reasons of simplicity, this value is fixed for all scenarios. The fairway and port dues are assumed to follow the number of trips at a fixed tariff. The insurance is assumed to follow the capital value. When the technology is proven to significantly improve safety, the insurance premium for Protection and Indemnity and Hull insurance, is expected to decrease in reality. The financial cost is in both cases 70% of the capital value with an assumed interest rate of 4.5% within 15 years. No subsidies are assumed. The chartering or freight broker service is considered also to be significantly automated in case of the AV which is assumed to a lower charterer’s provision of 1% while the CV has a rate of 7% of revenue. This is tested in the sensitivity analysis. The crew cost on the CV is calculated according the exploitation mode B for a vessel of 110 meter (CCNR regulation). The conventional vessel complies with the technical standards as set by S2 and requires two skippers (Rhine patented), one helmsman (four years of experience) and one boatman. A derogation for the AV is assumed. The automated docking system is assumed to detach in 10 seconds and needs maximum 30 seconds for mooring. A conventional ship needs a boatman and an helmsman to perform the operation which could easily take up to 10-20 minutes for every operation for an IWT vessel. Assuming that during the 10 hours trip, the vessel needs to perform minimum three mooring operations (e.g. passing a lock). The conventional vessel will take maximum one hour more than the AV with automated mooring devices. Annually, the conventional ship spends three till 6.25 days on mooring procedures while an AV will need five hours. This is a total time benefit of six days. Within those six days it is assumed that the AV performs three more additional trips (on average). Without a crew on-board, there are less communication costs. The communication with the SCC and other important actors during the trip are included in the SCC service costs when automated communication is not possible. At least 70% of the administration cost is related to managing human resources and is also taken in account. Based on a relatively short timeline of gasoil prices for the inland navigation [18], trends until 2060 are generated for the purpose of the SCBA. Without any dramatic changes, the price of crude oil is predicted to increase. An inflation factor of 1.8% is taken in account together with a 10% discounting factor. If always fully loaded, the annual revenue increases with EUR 118,096 in the first year of operation for the AV (scenario 1) compared with the CV (scenario 0).

5.2. Scenarios and sensitivity analysis
Scenario 0 relates to the conventional vessel (CV) without automation and with crew. Scenario 1 implements the automated and unmanned vessel (AV). All additional scenarios are variations with different assumptions. The cost/benefit analysis shows the net present value of every scenario which is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. The net present value shows if the project is profitable. The differences between net present values (NPV) of the CV and AV are first presented from a private enterprise perspective. The
NPV of the CV (scenario 0) equals EUR 3,741,767 and for the AV (scenario 1) EUR 4,744,269. All eleven scenarios are described by Table 2.

### Table 2. The Net Present Values of different scenarios with modified input

| Scenario | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|----------|---|---|---|---|---|---|---|
| Vessel   | CV | AV | AV | AV | AV | 5 AV’s | 5 CV’s |
| Payback time (years) | 15 | 15 | 25 | 15 | 15 | 15 | 15 |
| Fuel cost increase | high | high | high | small | high | high | high |
| Earnings | high | high | high | high | low | high | high |
| Charterer provision | 7% | 1% | 7% |
| SCC cost in EUR (year 1) | 0 | 190,960 | 286,440 | 0 |
| NPV in EUR (equity) | 1,384,550 | 410,915 | 565,858 | 642,372 | -2,143,143 | 5,968,490 | 6,922,750 |
| NPV in EUR (enterprise) | 3,741,767 | 4,744,269 | 4,889,341 | 5,301,335 | 139,807 | 30,789,368 | 18,708,837 |
| IRR (equity) | 22% | 11% | 12% | 11% | 5% | 13% | 22% |
| IRR (enterprise) | 15% | 10% | 10% | 10% | 5% | 11% | 15% |

The NPV is also viewed from both an equity perspective and an enterprise perspective. The latter perspective takes the equity in account and the debts on the level of the firm. To compare all scenarios of the sensitivity analysis with a more comparable reference scenario of the CV, the difference in NPV shows the added value of the innovation (Table 3).

### Table 3. The difference between the NPV’s of baseline scenario and innovation scenarios (in EUR)

| Sensitivity | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|-------------|---|---|---|---|---|---|---|---|---|---|---|
| \(\Delta\text{NPV}_{\text{equity}}\) | -973,655 | -871,214 | -1,023,826 | -1,497,340 | -924,260 | -143,289 | 782,431 | -1,538,986 | -669,429 | 209,713 |
| \(\Delta\text{NPV}_{\text{equity}}\) | 1,002,502 | 1,098,397 | 876,889 | 55,300 | 12,000,530 | 2,498,387 | 15,072,299 | -18,449 | 1,562,909 | 3,139,475 |

Scenario 6 is not mentioned in the last table, because this scenario is used as reference scenario for scenario 5 and 8. Scenario 11 scores better than the reference scenario. Increasing the crew from 4 to 6 FTE, gives more NPV for both perspectives. But in this scenario, both the CV and the AV do not meet the requirements from an equity perspective concerning the NPV. Scenario 8, where the SCC provides a relatively cheaper annual service rate and where scales of economy are made for five AV’s, the NPV becomes significantly higher in both perspectives. For the scenarios that describe variations on the basic null scenario of the CV, the discounting factor for equity does not show any negative results for the NPV. The scenarios with variations of the basic AV (scenario 1) are much more valuable which gives the height of uncertainty. If a better fuel technology is implemented, the fuel cost decreases and improves the NPV such as in scenario 3. The cash flow analysis shows a potential viable business case according to the assumptions but it is not better than the CV in comparable scenarios if the critical level of crew cost (6 FTE’s) is not reached. Which means that if less than 6 crew members are hired, the CV still performs better in every scenario. When the number of the FTE’s is equal or more than 6, the performance of the AV becomes more interesting and provides a better business case within this model.
5.3. Adding the social costs and benefits
Social costs are considered to be the needed upgrade of the infrastructure (automated mooring devices at locks if on-board devices would fail; communication systems with the AOS; and SCC’s if chosen for state-control). The social benefits are considered to be the decrease in accident and emission costs.

Infrastructure: The one-time investment for automated mooring devices in locks is estimated at EUR 814,448,048 and is based on a number of 272 identified locks in the EU-28 with each on average an installation of four devices or in total 1,088 units. Assuming that the EU and its Member States would pay for the additional infrastructure during the first year of operation, the current annual investments increase with 25%. This leads to the assumption that the given external cost per ton-kilometer for infrastructure will also increase with 25% (The external costs are calculated for each tkm which is performed by the vessel). Emissions: The differences in emissions lead to a roughly estimated reduction of EUR 175 million for emissions in the first year of investment for the EU-28 in a completely automated mode of IWT. Another assumption is that the emissions stay stable during the lifespan of the vessel. As explained, no modal shift is taken in account. If a modal shift (e.g. road haulage to IWT) would occur, there would be additional social benefits such as the reduction of emissions, congestion, noise, road infrastructure costs, etc. but this lies outside the scope of this article. The total annual external costs of the CV in the first year of operation are EUR 572,997 (scenario 0). For the AV scenarios, the assumption was made that the fuel consumption would decrease with 20% together with the related emissions and climate change cost. The accident costs are assumed to be zero. The additional EUR 2,000 euro on the port dues and fairway fees for the AV to cover partially the investment by ports and the waterway managers, is now removed to avoid double counting because the external cost of infrastructure covers the additional cost for the AV infrastructure.

Table 4. External costs of baseline scenario and scenario 1

| Scenario | 0 | 1 | 12.5% infra | 0% infra |
|----------|---|---|-------------|---------|
| External cost per vessel in EUR | CV | AV | AV | AV |
| Accident costs | 7,497 | 0 | 0 | 0 |
| Infrastructure costs | 138,000 | 193,545 | 174,191 | 157,623* |
| Emission cost | 427,500 | 383,724 | 383,724 | 383,724 |
| Total external cost | 572,997 | 577,269 | 557,915 | 541,347 |
| Compared with baseline scenario | 0 | -4,272 | 15,082 | 31,650 |

As explained, the performance of the AV is assumed to be higher than the CV. Therefore, the infrastructure costs are higher. The AV becomes less costly for society then the CV, if the additional infrastructure cost lies below 25% increase in this example. The external costs are also considered unimodal for the IWT. In the real world, the additional infrastructure costs will have to be compared with developments in other modes of transport. When external costs such as congestion are included, IWT becomes more attractive. A strong competitive and innovative inland waterway transport could lead to a modal shift from transport modes with higher external costs or at least could help the IWT to maintain the current modal share. If these social benefits are taken in account, the AV scenario would probably score better than within the limits of this approach. Another finding is that the safety benefit for IWT is rather low. Not many accidents occur on the European waterways with human decision making.

6. System of innovation approach
The system of innovation approach (SIA) highlights in this article, the failure and success factors of the innovation. These factors are presented in a matrix and are linked to involved parties and stakeholders. The main innovators are research institutions and innovative enterprises which have established an international network with authorities and industries during the current initiation phase.
Table 5. Systems Innovation matrix of the initiation phase of a fully automated and unmanned vessel.
black shaded cells = identified failure factors. Grey shaded = identified success factors.

| Institutions | Actors | Demand: VO/O’s, large vessel owners, charterers, industry with own vessels | Shippers/forwarders | Third parties manufacturers, consultants, sector organizations | lobbyists, funding, standardization bodies, |
|-------------|--------|--------------------------------------------------------------------------------|-------------------|---------------------------------|------------------------------------------|
| Infrastructure |        |                                                                                  |                   |                                 |                                          |
| Hard Institutions |    |                                                                                  |                   |                                 |                                          |
| Soft Institutions |    |                                                                                  |                   |                                 |                                          |
| Weak Networks |        |                                                                                  |                   |                                 |                                          |
| Strong Networks |    |                                                                                  |                   |                                 |                                          |
| Capabilities |        |                                                                                  |                   |                                 |                                          |

The identified factors are market (is there supply and demand), infrastructure (digital and physical), hard and soft institutions (regulation, culture, values and believes), capabilities (external knowledge and financing) and network aspects (influence of actors, too weak or too strong connections). The waterway manager or private terminal operator provides sufficient infrastructure (digital and physical), while other actors need to guarantee cyber safety, allow the new technology to be developed and solve the legal issues concerning liability, crew and technical requirements. Shippers, forwarders and vessel owners, of course also have their role regarding the infrastructure and learning capability to be able to work with the new technology. A knowledge network of institutions is identified at a global level. Hard institutions and the lacking of mooring infrastructure are important barriers for the AV. At the side of lobbyists and manufacturers, several players are identified with a strong network with different institutions. The branch organizations and labour unions do not show any resistance, although this could be the case when implementation is reached.

6.1. Infrastructural conditions
An AOS that only performs navigation tasks (with crew on board) does not need any fundamental changes in physical structure. The system should be able to identify the existing infrastructure (including signalizations) and perform accordingly in a safe and reliable fashion. In this scenario, only the wheelhouse could be unmanned, but not the entire vessel. In case of a truly unmanned vessel, the infrastructure needs an upgrade or make-over. Bollards are replaced by automated docking stations. On-shore pipelines or tank interfaces (bunkering or if the AV is a tanker barge), cranes and other relevant equipment is upgraded in order to attend unmanned freight vessels (both liquid as dry bulk, containers, project cargo, etc.). Bunkering facilities are redesigned for automated use. The communication infrastructure is able to allow safe, secure and reliable communication with unmanned vessels. In reality, most described tasks (and in expectation of a slow changing infrastructure and regulation) still need a crew on-board in the upcoming years. However, as modifications on the infrastructure side progress, more trajectories will become possible. The infrastructure to support unmanned vessels already seems feasible, but still needs to mature and comes with a significant cost (e.g. the quayside equipment for the Yara Birkeland is estimated at USD 20 million [19]). The digital structure could be even more challenging concerning big data exchange and data security. Policy plays an important role in safeguarding a secured digital infrastructure, however this issue goes broader than inland navigation only. In every sector, the problem to secure data and to ensure continuous data synchronization in real-time occurs and poses a global challenge everywhere. The issue of piracy exists in the maritime transport, but this is not the case for European inland navigation. Although the use of expensive robotic systems and the value of the cargo, could require a sufficient level of security against theft or even vandalism. On an unmanned vessel, these security issues will require secure data connections and presumable follow-ups by human or robotic interaction. Automated infrastructure brings other issues that eventually could lead to failure. The issue of liability could be the reason not to use automated terminal mooring devices. If something goes wrong, the berth operator could become responsible [20] and not the crew on-board which is the case with a conventional bollard and ropes.
6.2. Interaction conditions

If the innovator is not linked to an innovation network, chances for failure could be high. Also, if the innovator is too strongly linked, vital information outside the network can stay hidden. There are hardly any interactions identified between innovators that are focused on automation in different transport modes. Innovators, as most policy makers do, tend to have a unimodal focus. Only maritime and inland navigation are often linked, but this could lead to wrong conclusions and outcomes [21]. IWT is a relatively small sector at the European level and most EU-countries do not have a strongly developed waterway network. The institutional network at the European level reflects this reality which is further analysed in the INN-IN report. At the side of the main lobby organizations of the branch of the sector, the network is also considered weak. This weakness manifests itself in the scattered opinions between the numerous branch organizations across Europe towards different layers of policy and customers. A more efficient lobby could help to put important IWT issues higher on the policy agenda. Although, since 2018, closer cooperation between the different organizations has become noticeable on all policy levels with the creation of the European IWT Platform between EBU and ESO. A lot of effort needs to be done to strengthen the network which could be beneficial for all innovations. This is true especially when lobby work is in direct competition with lobbyists from other transport modes, aiming at the attention of high level policy makers. Innovation requires sufficient capacity during research, design, initiation, development and the implementation stages. In all stages of innovations, challenges could arise, and without sufficient capability the innovation could fail. The capability of the innovator is not only financial. Firms, especially small firms, may lack the capabilities to learn rapidly and effectively and hence may be locked into existing technologies/patterns, thus being unable to jump to new technologies/business patterns or develop an innovation themselves. The future deployment of automated inland vessels implies high development costs, low-scale production and a lack of mass consumer availability. The initial costs are considered relatively high at this stage of initiation. A fully automated and unmanned vessel includes the development and implementation of other innovation elements such as new technologies to replace all essential processes on board to navigate, and in following phases, to (un)moor, (un)load, maintain the engine room, supervise loading while constantly adjusting on all irregular weather conditions, and different waves and tides. The reduction of personnel cost, fuel cost and safety cost are the main identified drivers to have a return on investment for a private investor. Furthermore, regulation could possibly be lagging behind, despite the efforts of policy makers, what could influence the intended operation mode of the vessel and increase the costs even more because of the delay. When automated processes are allowed to replace or decrease the mandatory crew size, the AV could make a more positive business case. Uncertain policy in this regard can lead to failure. The innovation in this phase needs sufficient machine learning that can be achieved by gathering and sharing data, real-time field experiences and simulations of as many situations as possible. A complex innovation such as an automated vessel requires more specialized expertise for automated operations and inspections. Asymmetrical information could occur between public and private actors or even between the different subcomponent manufacturers and the integrated AOS manufacturer, which could lead to system failures in a worst case scenario or compatibility issues. Evaluation capacity is needed during the development and later implementation phase of the innovation, especially within inspection and regulatory standardization bodies.

6.3. Institutional conditions

The Netherlands and the Flemish region decided to transform their waterways into one transnational experimental zone for new innovation in IWT (except the international rivers) with an official permit of the waterway manager. Norway, the Russian Federation, China and Japan are doing comparable actions. The demand for a regulatory framework at European level with legal definitions is also emerging with proposals and debates at the river commissions, EC and UNECE. For example, the European Commission has shown special interest by accepting funding schemes for several automation programs and developments in all transport modes. The policy decision makers play a
crucial role in granting derogations and adjusting regulation to further develop and implement this innovation. If automated vessels have to comply with existing crew regulation according to their exploitation mode (A1, A2 or B), the business case behind this innovation could be weakened and lead to failure, because the main private benefit of cost decrease and efficiency would not be allowed to reach. The influence of variables during the innovation process such as soft institutional conditions (politics, cultural values and social aspects) and hard institutional conditions (rules and regulations) can be determinant for the diffusion of the innovation. As in maritime transport, a number of IWT regulations needs to be addressed in order to make the development of automated navigation possible. Legal definitions and other regulatory aspects have to be addressed by all actors in the multileveled governance structure of the (Pan-) European inland navigation and perhaps be adjusted or developed into a complete new set of rules. A scenario where regional or national states define automated vessels and draw up regulations, can be problematic for an international sector such as inland navigation. It would drive the costs of this innovation up because of additional compliance costs for each regime. The next table shows the different levels of policy and the relevant regulations that could have an impact on the levels of automation.

### Table 6. Layers of relevant affected IWT crewing and technical legislation

| Institution  | Technical requirements                                      | Private law issues (ship-owner and other commercial partners) | Other rules (criminal, public law etc.) |
|--------------|-------------------------------------------------------------|---------------------------------------------------------------|----------------------------------------|
| National     |                                                             | e.g. Belgian law of river chartering (Wet op de binnenbevracht°1936) | Labour provisions                      |
| River Comm.  | RVIR                                                        | CLNI                                                           | RPR (police)                           |
| CESNI        | ES-TRIN                                                     | CLNI                                                           | CESNI/QP                               |
| EU           | Ship safety directives & regulations, crew requirements     |                                                               |                                        |
| UNECE        | ADN (in case of automated dangerous goods transport), CEVNI | CMNI                                                           | CEVNI (police)                         |

Furthermore, there is no clear funding mechanism. European Member States (EU MS) can provide financial support according to EU rules (such as de minimis rules) next to rather limited EU funding programs (such as Horizon 2020 and CEF) for the IWT. Other institutional actors such as the River Commissions do not provide financial aid. The Flemish and Dutch government created a framework for the deployment of what they call smart shipping which refers to highly automated vessels, traffic management and infrastructure, interaction between ships and logistical parties, and interaction between vessels, regulators and inspection. The latter action is driven mainly from the perspective of a public actor that looks for ways to automate inspections, decrease traffic management costs, and achieve efficiency and effectiveness benefits in further automation of the fleet. However, the way waterway managers and other administrative units deliver their service is still quite archaic. In many cases, the crew is still obliged to keep hard copies of service booklets, loading and vessel documents at offices at a lock, a terminal or refinery. Also, the contracts between the customer and vessel owner still often demand paperwork in hard copy. Government is evolving, but in a much slower pace. A lack of sufficient level of e-government (e.g. online document transaction) can slow down automation of all vehicles. Another aspect is the inspection and enforcement challenges of a fully automated vessel. Inspectors need knowledge of automated vessels and other technology on board, and specialized training. Again, even for inspections, there are still differences between EU MS. For example, the Netherlands demand inspections every seven years in dry dock, while Belgium demands it every five years, which increases the compliance costs of the enterprise between Member States and would also have an influence on the AV. The absence of a vessel owner on board, causes challenges with regard to liability. In inland navigation, the captain is responsible for the cargo until unloading. If a ship is fully automated without a crew, a new legal solution is not only necessary for some important practical issues, but also a clear liability clause is needed. A legal definition and description of competences [22] of the external captain at the SCC (or on-board caretaker), can help partially to meet this liability challenge. Barriers in soft rules depend on the identified window of opportunity. Public as
well as private innovators and institutions are aligned behind the objective of being the first innovator with a completely automated vessel that could be unmanned and which is inspired by breakthroughs in other transport modes and robotic research. The soft actions within standardizing bodies (e.g. CESNI) have to be kept aligned and open for derogations in order for the innovation to be successful. The lack of alignment in both soft as hard rules can represent additional barriers as the innovation proceeds. Cultural institutions comprise typical characteristics of contemporary inland navigation in Europe. However, it is important to point out that because of historical reasons, there are many differences between the business structure in the fleet that is active on the Rhine and the one on the Danube. The traditional vessel owner/operator (VO/O) in the Rhine region, has a more family-orientated business (mostly with family on-board), whereby more luxurious accommodation is an important issue. The degree of commitment of a VO/O to its vessel, could be of importance in comparing with an external captain in a SCC. For most VO/O’s in the Rhine fleet, the vessel is everything they have. It is their family house, job and company. The personal attachment with the vessel and the logical consequence that safety does not only concern the transported cargo, could lead to more effort in protecting the ship than the safety incentives and level of attachment at a shore control centre. Furthermore, when reduced to an on-board caretaker, the VO/O could feel less attracted to work on an automated vessel with merely a fall back monitoring function. The existing VO/O’s could find it less appealing to work in a SCC. In the medium-long run, the VO/O or external captain will also gain less navigation experience, which lowers the quality of the work force that should be able to intervene. Hetherington et al. [23] point out that automation still needs attention of the crew, or in case of unmanned navigation of the SCC. However, automation can lead to too much reliance on machines with less monitoring and caretaking as a consequence and to new human weaknesses, amplifying existing ones. Lützhöft and Dekker call this a certain kind of cognitive lackadaisicalness [24]. More sociological and psychological research is needed to measure the possible differences in operational and safety quality from a shore operator in distant “gaming mode” and a vessel operator who is protecting his or her life, family, house, company, cargo and private belongings. Furthermore, the existing working force will have to be re-educated for other assignments in a strong automated and more complex world. But as the labour shortage grows in the current European IWT, it will be rather more challenging to replace the ageing crew of the Rhine fleet by human crews. The level of conservatism can be relatively high. Existing operators and other actors will doubt safety and reliability of all the new developed technologies. In a time when automated crafts are going in to space to dock at the ISS (since the nineties), there are still those who believe that it is too difficult or even impossible to develop fully automated and even unmanned vessels for the inland waterways. Resistance and general disbelief could prove to be important aspects to tackle. It is definitely not proven that an SCC will be safer indeed. Issues such as situation unawareness, planned obsolescence, data misinterpretation, capacity overload, reliable connectivity and as mentioned the lack of emotional attachment should be examined closer from a multidisciplinary perspective (socio-medical, computer science, psychological). Ports such as Rotterdam and Antwerp are organizing together with waterway managers, experiments with automated vessels, so any port resistance for the moment looks most unlikely. It is also possible that some customers are not willing to entrust their valuables with these kinds of “robots”. Unmanned, automated, remote - controlled or autonomous vessels will have to prove that they are trustworthy and above all safe and reliable.

7. Conclusion

The combination of the quantitative approach of the SCBA and the qualitative systems of innovation approach gives a comprehensible in-depth view on the current initiation phase of automation in the European inland waterways. Defining the automated and autonomous vessel, is already quite challenging and is still open for debate. The number of uncertainties of failure factors concerning automation, but also the relatively low benefit in replacing the crew of a conventional vessel by an SCC service, gives less incentives to invest in a AV. But when competing modes become automated, the inland navigation could lose market share or even be pushed out the market. But it is also perfectly
possible that a number of customers would still prefer a crew on board and that the market of CV’s will not seize to exist. The uncertainties are not only related to the fact that a number of technological concepts are still in the initiation phase and need maturation before they can be implemented, but also to the difficulty to calculate the service price of an SCC before even there is a market of SCC providers. Starting from a certain crew size (in the model 6 crew members), the automation becomes more interesting for private investors. From societal perspective, the safety benefit in IWT is relatively low because of the low number of accidents on the European waterways. The reduction of emissions and greenhouse-gases is caused by the lighter design and more efficient sailing. The effect on modal choice and the potential for modal shift from road was not examined in this article, but this could also lead to additional social benefits.

The more data is being gathered about a ships’ behaviour and navigational skills (machine learning), the more the actual navigation and propulsion can become automated and even autonomous. In this case, it is important to distinguish among the different automated ship systems (subcomponents and robotics included) and not only among the automation levels. Infrastructure (physical and digital) needs to be addressed and the regulators should decide in a technology neutral way if mandatory crew sizes can be reduced by adding automation while complying to existing safety standards. The liability issue needs answers on both shore and vessel side. Funding remains an issue and it is questionable if a fragmentation of scarce means adds to the development of IWT automation. This study was the first attempt to examine AV’s in IWT by using SCBA and SIA. Further research is necessary to explore broader possibilities and more scenarios.

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