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# The Drivers, Barriers, and the Actors of the Autonomous Inland Shipping: A Systematic Review

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## Abstract

The freight transport activity in Europe is projected to increase by around 40% in 2030 and by little over 80% by 2050 [1]. The rapid growth of inland transport demand in Europe would bring burden to the road and railways transport in the future. Meanwhile, the transport sector contributes to 25% of EU's total greenhouse gasses emission [2]. One of the solutions proposed is to shift 75% of today's freight to railways and Inland Waterways Transport (IWT) through the European Green Deal[2]. Compared to other modes of inland transports, the IWT is characterized as low cost, safest, and least noisy[3].

There are 5,867 registered European inland fleets which consist of 4,922 EU and 950 non-EU flagged fleets in 2022 [4]. There are three dominant types of vessels on the European waterways: self-propelled barge; tug and pusher; and dumb and pushed vessel [5]. The main types of goods transported by the IWT in the Europe are metal ores (25.5%); coke and refined petroleum products (15.3%); chemicals, rubber and plastic, and nuclear fuel (11.9%); and agriculture products (10.9%) [5]

Unfortunately, the current IWT is not competitive enough compared to other inland transports, including railways and road transport. The autonomous IWT concept is proposed to increase the competitiveness with its advantage in safety, environmental, and costs. The autonomous maritime systems can reduce the cost, emission, and reliance on humans [6]. The purpose of this paper is to identify the actors, drivers, and barriers of the autonomous IWT.

This study uses systematic review with the PRISMA 2020 framework to capture data from published articles[7]. The main actors identified from this study are the shipping companies, International Maritime Organization (IMO), terminal operators and ports, local and regional regulatory bodies, flag states, and the communication providers (Vessel Traffic Services (VTS) and Sea Traffic Management (TSM)). The identified drivers are lower crew costs, safer and more efficient operation, lower capital and operational costs, and attractive working conditions. The identified barriers are higher building costs, extra port fees, higher human competence, innovative business models, new regulations, and new added costs.

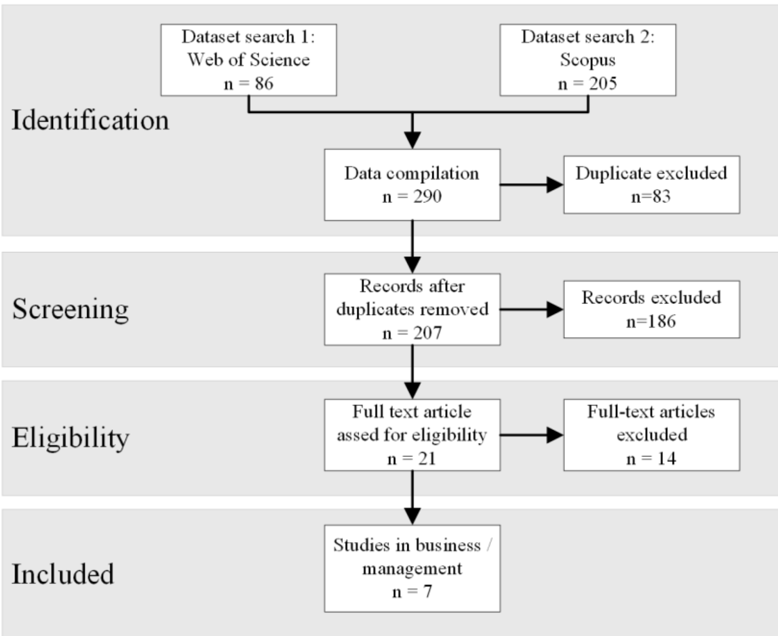


**Figure 1** Data selection flowchart

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Autonomous Inland
& Short Sea Shipping

# Assessment of the economic feasibility of autonomous ships for short-sea shipping

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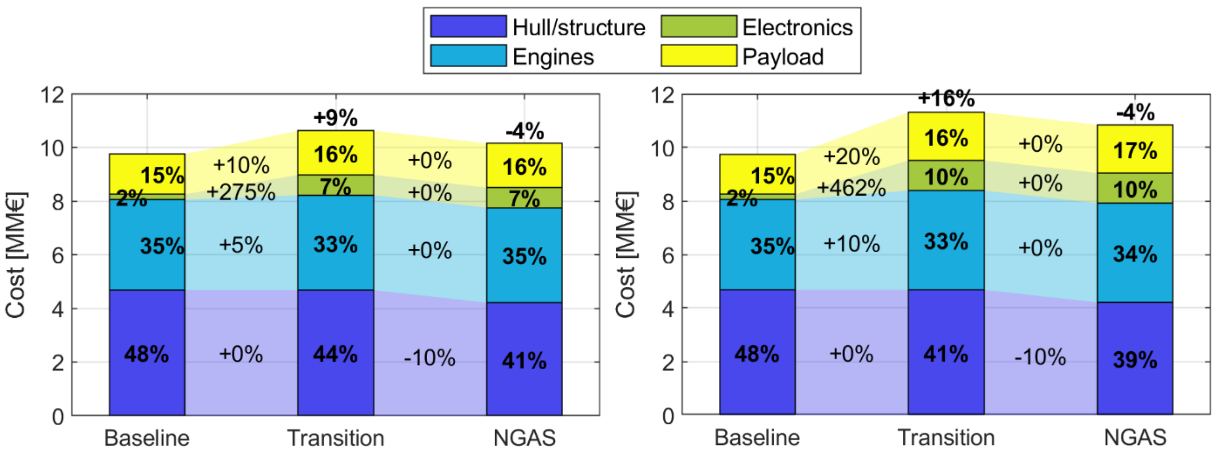
## Abstract

The development of autonomous ships has accelerated during the last decade due to the technological advancements that allow safe autonomous navigation, as well as the need to address several challenges including sustainability and resilience of shipping operation as well as potential seafarers deficit in maritime industry. Despite today's autonomous ships demonstrators and initiatives, such as Yara [1], Meguri 2040 [2] and AUTOSHIP [3], the lack of information on the related costs, the need for infrastructure/government investments, the actual technology readiness level, and the uncertainty of the future global economy render the Maritime Autonomous Surface Ships (MASS) viability analysis challenging.

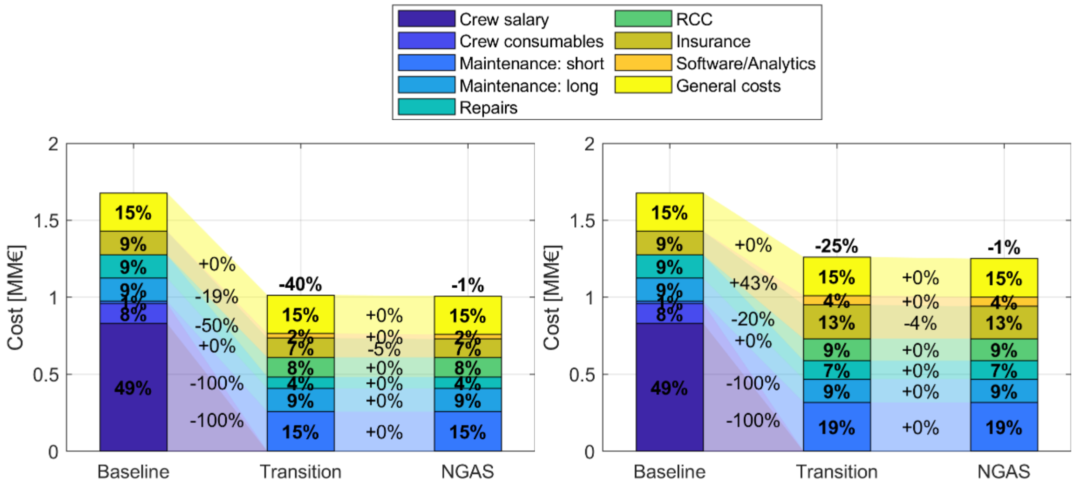
Focusing in short-sea shipping MASS, this study presents a methodology to verify the economic feasibility of autonomous cargo ships, using the net present value method. Methods are developed to estimate the capital expenditures (CAPEX), operating expenses (OPEX) and the voyage expenditures (VOYEX) with data available in the literature grouping them in several subcategories. The following two scenarios were considered: (i) retrofits/conversions of existing ships to operate autonomously; (ii) new design and newbuilds of the Next Generation of Autonomous Ships (NGAS) to operate crewless.

The results of this study (illustrated in Figures 1 and 2) demonstrate that even with a higher CAPEX (6% to 12%) the autonomous ships operation will have a higher profit margin, due the lower OPEX (–25% to 0%) and VOYEX (–3% to –8%). This can additionally facilitate the use of greener technologies and alternative fuels, such as hydrogen or ammonia, thus achieving the IMO emissions reduction goals (IMO GHG Strategy [4]), which can be particularly important for MASSs operating in the Emission Control Areas (ECAs) that are subjected to stringent emissions limits.




(a) Best scenario (b) Worst scenario

**Figure 1** Overall CAPEX costs for autonomous ships adoption




(a) Best scenario (b) Worst scenario

**Figure 2** Overall OPEX costs for autonomous ships adoption

## Acknowledgements

This study was carried out in the framework of the AUTOSHIP project, which is funded by the European Union's Horizon 2020 research and innovation programme under agreement No 815012. The authors kindly acknowledge the comments, input and feedback provided by the AUTOSHIP partners. The opinions expressed herein are those of the authors and should not be construed to reflect the views of EU and the AUTOSHIP partners.

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Autonomous Inland & Short Sea Shipping

# Methodological approach towards amending regulatory, legal and liabilities frameworks for MASS

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## Abstract

The current regulatory, legal and liabilities frameworks for conventional ships have been developed considering the presence of crew on-board for performing the ships' navigating/monitoring/maintenance operations. For autonomous ships, however, the human involvement is expected to be moved from the ship to the shore control centre. This disruptive shift requires new stipulated regulations and corresponding amendments of the current regulatory framework both at international and national/regional levels.

This study aims to present a methodological approach for mapping, gaps analysis and identification of priorities pertinent to the legal, regulatory and liabilities frameworks for the design and operation of Maritime Autonomous Surface Ships (MASS). The followed methodological steps are illustrated in Figure 1 and are grouped into the following three stages: (a) existing stage; (b) transition stage, and; (c) next generation of autonomous ships. Existing stage does not consider/allow the MASS operation. Transition stage considers/allows the MASS operation (new built or converted/retrofitted conventional ships) keeping the human in the loop (by considering the human operator in the shore/remote control centres). Next generation stage considers MASS to autonomy level 4 according to IMO [1], i.e., no human involvement.

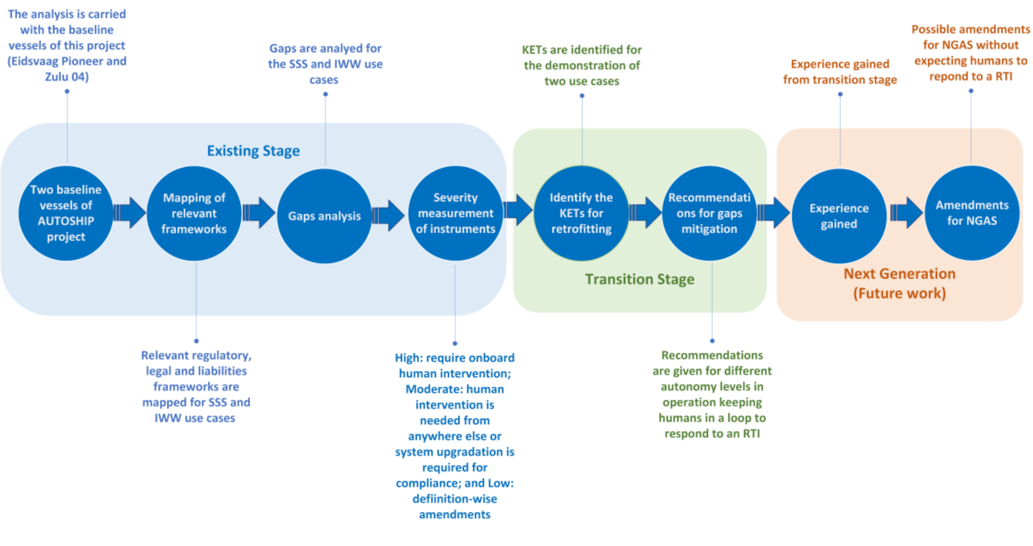


Figure 1: Methodology flowchart

The analysis of the existing stage commences by considering the two use cases of the AUTOSHIP project [2], namely the short sea shipping (SSS) and inland waterways (IW) MASS, and performs the mapping of the existing regulatory, legal and liabilities frameworks pertinent to ships' autonomous operations. The existing frameworks consist of several regulatory bodies (e.g., SOLAS), which provide a number of instruments (e.g., clauses in SOLAS chapters and sub-sections) requiring specific provisions for the operation/maintenance. This study continues with reviewing the prevailing regulatory, legal and liabilities frameworks, as well as recent studies [3–5] and reports of autonomous shipping projects, such as, MUNIN [6,7] and MEGURI 2040 [8], to identify the existing frameworks' gaps. Based on these gaps, the severity levels of the analysed instruments are classified as high, moderate or low, considering the degree of the human involvement to comply with existing provisions, the need for introducing/proposing appropriate amendments, as well as the anticipated timelines for the approval of these amendments in national/international levels.

The analysis for the transition stage focuses on mitigating the identified gaps in the existing stage by utilising Key Enabling Technologies (KETs) for remote and autonomous operation. To effectively address these gaps, this study refers to the outcomes of the Regulatory Scoping Exercising (RSE) [1] and the proposed four alternative ways to address the instruments by interpreting, amending, developing new instruments, or not applying changes. Moreover, four degrees of autonomy are considered as identified in RSE for SSS, whilst CCNR [9] autonomy levels are selected for IWW case.

The next generation stage analysis is considered out of this study scope, as the developments of the transition stage need to be first established. The experience gathered during this transition stage could be beneficial for implementing further amendments of the instruments required at the transition stage or developing a separate MASS code dedicated to NGAS operation.

This study is expected to assist the MASS stakeholders to prioritise the instruments which would require amendments whilst preparing the roadmap for MASS adoption.

## Acknowledgements

This study was carried out in the framework of the AUTOSHIP project, which is funded by the European Union's Horizon 2020 research and innovation programme under agreement No 815012. The authors kindly acknowledge the comments, input and feedback provided by the AUTOSHIP partners. The opinions expressed herein are those of the authors and should not be construed to reflect the views of EU and the AUTOSHIP partners.

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# Introduction to the Open Simulation Platform, Open Source Co-Simulation and the DNV Simulation Trust Center

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## Abstract

For autonomous systems to materialize and be accepted by authorities and society, trust is indispensable. Establishing trust in highly automated and autonomous systems, though, requires new ways of assurance.

Not only become systems more complex. Complexity can be dealt with by modularization. This is as true for software driven systems as it is proven for hardware driven systems.

The bigger challenge lies in the fact that software, in contrast to hardware, is subject to changes. And: the introduction of changes in software is not an exception. Changes aren't *deviations* from a plan.

As engineers we might not exactly feel comfortable arguing changes *are* the plan. Yet, they are.
Agile development? DevOps? Think about it.

Trust in autonomous systems, though, is not an option. The form of *how* trust is being generated will change, however. Trust cannot any longer be built upon expertise alone. The related processes are simply too slow. Manual risk assessments are as important in the future as they were in the past. But a risk assessment workshop for a complex system cannot be repeated every time a software change gets introduced.

To cope with agile development cycles, existing and well-established methodologies of assurance need to (at least) be complemented by automated means of generating trust.

In assurance, as a fundamental means of generating trust, we can expect a shift from expertise based to evidence based trust. Not because it is cheaper, more efficient or in any other aspect economically more viable. But because there is no other option.

Imagine you have a highly automated system (and feel free to draw the line for 'highly' at your appetite). Assurance has gone through all means of proven methodologies. Prescriptive rule sets by class and authorities are followed, risk assessments are done, safety measures are drawn and implemented. Policies, procedures and technologies are in place. You can very reasonably be sure you have a safe system. No doubt whatsoever.

Now, following commissioning and trials, one of the component manufacturers needs to implement a change in his component's control system. What is the effect of this change on the overall system's safety?

What expertise is needed? And who owns this expertise to judge on the consequence?
Is the system still safe? To what *degree* is it safe?

Stop thinking. With expertise *alone*, there is hardly a way to responsibly solve this.

Don't get me wrong: Established methods of assurance are well proven. They work excellent. They are exactly right. No plane would fly, no vessel would sail if these methods weren't established, duly maintained and responsibly applied in all safety critical industries. The thing just is: All these methods are not exactly great in coping with changes (Which is why we always wanted changes to *stay* an exception).

With the rise of autonomy, this condition no longer holds.

For trust in autonomy, new forms of assurance need to be researched, developed and established. Trust through expertise needs to be complemented with trust through evidence. *Automated* evidence.

For this to happen, two developments for me are key: Simulation and model based safety. Simulation, in fact, will evolve from an isolated engineering tool to an integrated part of assurance. There will be no trust in autonomy without trust in simulation. Simulation models become digital artefacts with an identity. They become part of the trust chain. Simulation models will come with responsibility and liability. They will be traded, exchanged and: co-simulated.

This talk will provide an introduction to co-simulation and two related initiatives in this field: The Open Simulation Platform (OSP) and the DNV Simulation Trust Center (STC).

# Ability Marine Pilot Family
# – ABB Marine's development toward Autonomous Shipping

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## Abstract

This presentation is intended to update potential research partners and authorities on the product developed related to bridge solutions within ABB Marine and their application potential for the Short Sea and Inland Sector.

ABB Marine Pilot Family is the strategic product family that aims to enable autonomous navigation. It has been launched to provide our customers with autonomous and remote operation-ready products that can be widely used as soon as the regular framework allows and enables our clients to achieve safer operational performance. The product family is composed of Pilot Control, Pilot Vision and Pilot Decision. The two former interface with the standard navigational equipment on board and can be used to provide manoeuvring and decision support to the crew. The latter is the autonomous decision-making tool that uses the manoeuvring and situational awareness information to enable autonomous navigation of the ship.

Pilot Control enables functionalities such as all-speed joystick control, optimized thrust allocated, position keeping, or active wind compensation. While this product has been targeted towards mostly azimuth propulsion for complex manoeuvres of for instance tugs, it is also proving itself for the application on direct drives as shown by the series of Lisbon fast ferries that will be in operation in the near future.

Pilot Vision is a continuously reliable advisory system for enhanced situational awareness on board or a shore. It harnesses sensor technology, computer vision and sensor fusion, to provide better visibility, as well as aid to understand distances to stationary and moving objects. The functionalities help to be aware and assess risk and prioritize targets.

The first application of autonomous decision-making with pilot decision has been demonstrated earlier this year in the autonomous collision avoidance tests with the Keppel tug. The Singapore-based tug now not only has full complete control capabilities but is also the first vessel with ABS-certified autonomous operations.

ABB Marine has been involved in inland navigation research projects that are looking into new energy solutions. Considering these and the Pilot Family, we have the expertise to integrate the majority of the onboard systems for the next-generation vessels. With the intention to place focus on the large potential of the inland and short sea shipping markets, we are looking for experienced partners with whom we can collaborate to provide reliable technical solutions to the customers.

# A-SWARM Autonomous Electric Shipping on Waterways in Metropolitan Regions

## Towards real-time trajectory planning and control of surface vehicles

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## Abstract

The interest in unmanned surface vehicles (USV) and autonomous surface vehicles (ASV) in the industrial sector is growing rapidly. In large metropolitan regions with natural or artificial waterways, ASVs can be used advantageously for logistical tasks such as transporting goods or waste. Having many small autonomous units with electric propulsion can contribute to ecologically and economically beneficial transport alternatives and shifts some of the logistical processes from the road to the water, which relieves the intracity traffic. Such concepts are being investigated in a number of research projects, including the German research project A-SWARM.

In the future, the trend is increasingly towards unmanned vehicles that can be operated manually via wireless communication. To further increase efficiency, it must be possible to operate several vehicles simultaneously with the same number of personnel. This requires a higher degree of vehicle automation. In order to reach this, the project A-SWARM investigates guidance and control of small autonomous surface vehicles.

This talk gives an insight into the applied techniques, where guidance includes path finding in the presence of obstacles and upon that, the generation of a feasible trajectory. Using this, a control strategy can be applied to move the ASV along the trajectory. Besides technical details, recent experimental results will be presented.


## Literature

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# Build-up and Analysis of a Terrestrial VDES Test-bed for Inland Waterways

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## Abstract

The paper presents the world's first build-up of an inland terrestrial VDES testbed around Berlin on the Spree-Oder-Wasserstraße. In May 2022 we performed measurements on the waterways to analyse the coverage by using three base stations installed on the site of the WSV. With a vessel we collected received signal strength and signal to noise ratios on a 35 km route carrying a mobile VDES transceiver. The measurement data was analysed to assess the communications performance on board of a typical vessel. Further, the performance assessments were used to define a dedicated area that could be foreseen as an alternative positioning and timing area based on VDES R-Mode.

## 1 Introduction

The first revision of the VHF data exchange system (VDES) was published by the ITU in February 2022 [1]. VDES combines four individual communication systems. These four communications systems are:

- Automatic Identification System (AIS)
- Application Specific Message System (ASM)
- Terrestrial VHF Data Exchange (VDE-TER)
- Satellite VHF Data Exchange (VDE-SAT)

AIS operates as a mandatory communication system since 2002 for large vessels on the open sea. In Germany it became later mandatory on inland waterways for commercial shipping on large rivers such as Rhine, Mosel or Elbe. It is used for vessel traffic management and helps to improve the context awareness to reduce the risk of collisions. The build-up of the AIS network is nationwide in Germany ongoing. The area around Berlin is not yet fully operational. During the transition period the area could be used as potential space for testing. The project DSOW (Digital Spree-Oder-Wasserstraße) focuses, therefore, on building up a communication and navigation testbed together with constructing an autonomously operating vessel. Therefore, the project aims on demonstrating how urban areas could efficiently benefit from inland waterways. The intention is to exploit the period of the transition from an AIS-only network to a VDES network that would offer up to all four communication systems. The VDES is utilizing the marine VHF spectrum, and all four systems are spectrally closely with each other which allows conveniently to reuse known existing infrastructure. Therefore, the expectation is to ease the roll-out costs by operating with the existing AIS infrastructure, such as cabling and antennas, either on land or on the vessel.

For autonomous vessels redundancy of communication and also navigation systems are key. Today's mariners depend solely on GNSS. Therefore, VDES as a communication system has an additional navigational functionality integrated. A dedicated ranging signal together with navigational information is broadcasted to enable the vessel to determine its location independent of GNSS. The additional functionality as a navigation system is named VDES R-Mode [2].

## 2 Test-bed Build-up and Measurement Campaign

The test-bed build-up south-east of Berlin is shown in Fig. 1. The area considers:

- Large waterways, such as the Müggelsee
- Narrow channels with rules for limited speed
- Medium wide channels (Dahme)
- Water-locks, e.g. at Wernsdorf
- Low bridges
- Hilly terrain

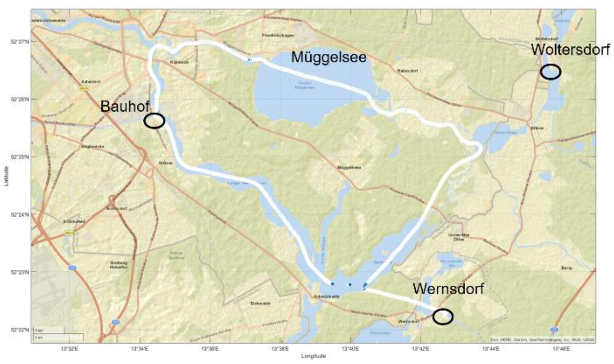


**Figure 1** Test-bed area for land-based VDES infrastructure (black circled areas) and route (white line)

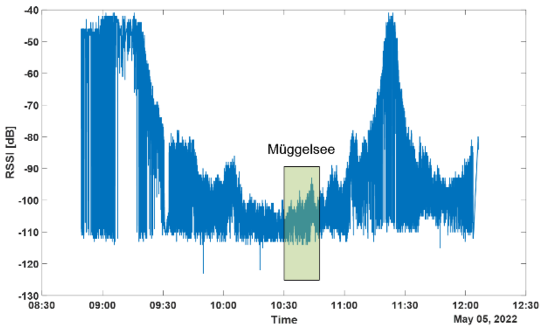


**Figure 2** RSS of all three base stations. The colored area in the middle represents the Müggelsee.

The land-based build-up uses the current existing infrastructure setup by the WSV, which includes masts with heights of 20 m above ground.

We travelled with the vessel Fürstenwalde operated and owned by the WSV. The used VDES1000 units measured the received signal strength (RSS) and the signal to noise ratio (SNR) from all four VDES1000 units sequentially and continuously. The drive started at Wernsdorf and passed the water-lock. After this the vessel went north towards Woltersdorf where the second base station was located, to turn west towards the Müggelsee. After the Müggelsee we crossed several bridges, and especially the bridge "Lange Brücke" with its low height. Travelling along the Dahme towards Wernsdorf again closed the loop of the measurement drive.

## 3 Analysis & Conclusion

Apart from the VDE communication service an additional navigation service based on VDES R-Mode could be applicable if multiple base stations can be heard. Therefore, the area around the Müggelsee is of interest. Our analysis showed that it is the only area that is covered by all three base stations. However, it is visible that the RSS is low, and therefore, the expected performance is limited. The early analysis shows that the locations of the existing AIS infrastructure are beneficial, but the performance operates partially borderline. Therefore, potentially alternative locations as gap fillers are currently considered.

The overall maximum RSS of all signals over the time period of the measurement drive is shown in Fig. 2. We will further discuss the measurement data in the final paper in much more detail. Especially the various locations of interest that are outlined in Section 2 are crucial as they are relevant for an autonomous vessel.


## Acknowledgement

The authors would like to express their gratitude for the invaluable support by the WSV. Further, the patience of their colleagues with our requests during the measurement was very helpful as well.

Further, we thank the DSOW project team for their support during the measurement.


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# Automating the Loading Process of Inland Tank Vessels

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## Abstract

Inland waterway transportation (IWT) accounts for 50 percent of the German liquid cargo transport volume [1]. Handling liquid cargo is regulated by well-established processes with clear technical and legal requirements. Not least because of these specifications, the processes have changed only slightly in the past. Deficits in terms of process reliability, efficiency and ergonomics are therefore part of the standard process. For instance, when loading or unloading inland tank vessels, heavy pipes and hoses have to be moved manually from the land side to the ship and vice versa. Before the actual transshipment process commences, the connection of the hose to the opening requires several manual preparatory steps while the personnel aboard holds the heavy hoses.

In view of the exacerbated shortage of skilled labor in the field of IWT, the attractiveness and comfort of the jobs needs to be raised, e. g. by providing relief from physical and mental stress. Automation can bring about such relief – and simultaneously lead to stable and reliable processes and productivity increase. In IWT, automation is already a trending topic. For instance, ongoing research is done on automation of navigation tasks [2]. However, in order to operate fully autonomous vessels in the future, automating the navigation tasks is not sufficient. In addition, tasks like the transshipment and cargo handling require dedicated efforts of automation and digitalization as well.

To optimize the handling process of liquid cargo, a set of simple technical solutions already exists that can be used in inland ports. Depending on the goods to be handled, the inland vessel and the port environment, these technical solutions for the transshipment of liquid cargo vary. Apart from the fully manual workflow, the technical solutions include hose reels, hose towers, and loading arms. While all of these solutions decrease the workload to a certain degree, none of them feature any possibility to automate the process of loading liquid cargo in the future. Only in terms of offshore LNG transshipment, some research towards automation has been conducted [3].

With the help of a collaborative robot (cobot), the loading and unloading process of inland tank vessels can be supported effectively as individual process steps can either be completely automated or executed in collaboration between a robot system and the human operator. Thereby, the robot acts as an auxiliary for the personnel involved. Thanks to the new possibilities for performing the individual work steps, safer and more efficient process sequences can be realized [4]. As a proof-of-concept, the system is to be further developed into a fully automated robot in order to show the technical scope of possibilities.

For conventional vessels, the use of a cobot to support the loading process promises to improve process efficiency, raise safety standards, as well as reduce physical and mental workload [5]. Apart from the support of conventional

inland vessels, automation of the loading process acts as an enabler of the future operation mode of automated inland vessels as well [6].

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# Drone Photogrammetry Workflow – Key Concept

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## Abstract

Scope of this paper is the key concept for structuring a workflow for autonomous drone photogrammetry. Simulation with a photorealistic environment plays an important role during the further development process for autonomous driving in all domains. The setup of such a virtual environment however is a time-consuming process and requires know how in the field of 3D modeling. Using photogrammetry is a promising alternative for the reconstruct of specific 3D objects. As shown by Jarofka et al. in [1], photogrammetry is generally applicable for the reconstruction of objects in the context of inland waterways. To achieve better results and to automate the process, it is essential to implement an (automatic) workflow. One of the most important factors in the reconstruction of objects using photogrammetry are different camera viewing angles [2]. In order to achieve high quality textures and dimensional accuracy, all parts of the object must be visible from multiple viewing angles. State of the art photogrammetry programs such as METASHAPE provide an algorithm for automatic detection of suitable viewing angles for a complete reconstruction [2, 3]. A prerequisite for this automatic detection is an already existing point cloud or model of the object. Since the object dimensions are not known in advance, a prior rough scan with the drone in a raster offers a promising alternative. The raster flight eliminates manual steps of measuring dimensions or the manual setup of a suitable flight path for the detailed reconstruction. Furthermore, object detection is used to determine the area of interest for the later reconstruction. Figure 1 illustrates the intended workflow for a detailed reconstruction.

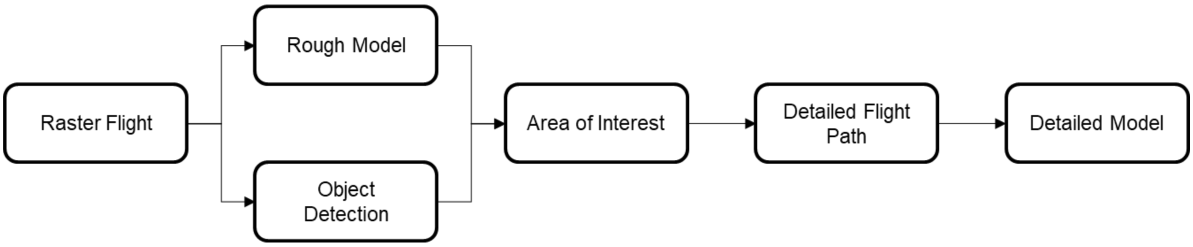


*Figure 1: Flowchart of the intended workflow*

Beyond the detailed reconstruction, the preceding raster flight can also be used to generate a DIGITAL ELEVATION MODEL (DEM) in the future. This DEM could provide information about the terrain with the corresponding heights [4]. These are necessary to combine the reconstructed models with height maps and other objects to a complete simulation environment.

Once the path for the raster flight or the path for the detailed reconstruction is generated, the drone should follow this path autonomously. Using the FLYLITCHI app, a path can be generated ahead on a computer and later uploaded to a mobile phone [5]. When controlling the drone, it is then able to follow the uploaded path. Thus, minimal user input is required to follow the waypoints of either the raster or the detailed flight path.

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# Reference Tracks for Automatic Track Control Systems

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## Abstract

This contribution focuses on the paths to be followed by track control systems. These reference tracks greatly determine the performance of trackpilots as well as their acceptance by the user. Well-designed reference tracks lead to reduced fuel consumption and increased safety.

Three different questions are raised:

- What does the user expect?
- How can reference tracks be generated?
- What are their mathematical properties?

# Localization of inland vessels in a waterway environment: Application of point cloud registration and SLAM approaches

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## Abstract

With the eminent interest in autonomous navigation comes the necessity to provide a reliable pose estimation of the ego system. Localization enables autonomous systems to estimate their pose with respect to the given environment. Common practice is to acquire this pose information from the Global Positioning System (GPS). However, the GPS can not be assumed as always reliable, especially in a GPS-denied environment. This contribution proposes a localization approach based on point-cloud registration to compensate for unavailable or unreliable GPS information.

Initial pose information is obtained from the last reliable GPS data available. As the system reaches a GPS-denied environment, the system starts to estimate its position by using scan registration. The scan registration is based on Normal Distribution Transform (NDT) and Iterative Closest Point (ICP). To improve registration performance, initial pose estimation is supported using different motion models. Heave as well as pitch and roll motions are neglected. The performance is tested for different combinations of registration algorithms and motion models in different scenarios using experimental data from the AutoBin project.

Supporting motion models can help to reduce the registration error. Besides that, the degree of freedom reduction also contributes positively to the overall performance. The results show that the localization accuracy can be improved by using the proposed method compared to the baseline lidar SLAM approach.

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# Towards Robust Navigation Solution and Flexible Sensor Fusion in Challenging Inland Shipping Scenarios

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## Abstract

Vessel navigation, whose history can be traced back as far as 4,000 years, is crucial for safety as well as modern planning and control approaches. Although this topic has been intensively studied in the last decades and plenty of industrial navigation solutions are available, accuracy and robustness are still not guaranteed especially in challenging scenarios such as crossing bridges, water locks, and crowded harbor areas. In these situations, a higher localization accuracy for collision avoidance is required, and the measurements of e.g., Global Navigation Satellite Systems (GNSS) used to estimate the vessel's states can be highly corrupted. In this contribution, we aim to summarize the drawbacks of state-of-the-art navigation solutions from a theoretical point of view and propose novel developments that provide a more robust trajectory estimation and enable flexible sensor integration. Lastly, the usability and economic impact of the new approaches are discussed.

In general, global position, orientation, and velocity data are necessary to operate automated ships. For this purpose, GNSS are generally used. Real-Time Kinematic (RTK) uses GNSS correction data from a local Ground Based Augmentation Service (GBAS) to enable centimeter accuracy with a standalone GNSS receiver [1]. However, such solutions are prone to high errors once the GNSS observations are lost or corrupted. To overcome this problem, most navigation solutions utilize the fusion of the GNSS observations with high-frequent measurements of an Inertial Navigation System (INS) using Kalman filtering [2-3]. A Kalman filter is an optimal state estimator if and only if the underlying assumptions of its derivation are fulfilled. As one of the most critical assumptions for optimal performance, the requirement for white noise distributed system model errors is typically heavily violated by corrupted GNSS observations in challenging shipping scenarios.

To relax the prerequisite assumptions of Kalman filters and improve the performance and robustness of the navigation solution, Benz et al. integrate a secondary speed sensor alongside the GNSS observations to perform the measurement update, which results in faster convergence behavior of the Kalman filter and enhanced performance during GNSS outages [4]. Our previous work [5] proposed a trajectory estimation algorithm using factor graph optimization for a tightly-coupled fusion of GNSS and INS observations. This approach was validated experimentally during a test trial along the Dortmund-Ems water canal. Compared to the conventional Kalman filter approach, the optimization-based algorithm with the integration of a surrogate motion model using Gaussian process regression shows prominent improvement both in the accuracy and smoothness of the estimated trajectory. Moreover, this approach enables a flexible framework to integrate more reference sensor observations, dramatically enhancing the navigation solution's robustness, as shown in work [6].

While a large research domain is working on GNSS signal availability, we highlight that there is also significant demand and a high potential for algorithmic development and sensor fusion technologies regarding the usability and economic impact of the navigation solutions. Instead of developing infrastructural measurement references, such as signal transmitters as proposed in [7], to guarantee the performance of navigation solutions, cheaper and more flexible sensors on board, such as cameras and LiDARs, can also be utilized to improve the state estimation performance. Furthermore, we also present our discussion on how Deep-Learning-based methods can enhance navigation solutions.

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# A Machine Learning Approach for Power Prediction of a Container Vessel to Improve Route Planning

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## Abstract

With the ongoing digitization and automation of the maritime industry, there is growing interest in data-driven approaches for the prediction of ships' power demand and finally the reduction of their energy, hence fuel consumption by smart route planning. The goal of the presented work is to develop a data-driven model for predicting the power demand of the main engine of a super post-panmax container vessel. Machine learning methods are applied to develop these models using historical operational data of the ship as well as weather data. Weather data is delivered from a weather data provider, while the ship's operational data is acquired on-board. Operational data from a number of voyages between Europe and Asia during about one year are considered. The process of data preprocessing as well as a comparison of different modelling approaches are presented.

# Key Issues for Realizing Safe and Reliable Future Generations of Inland Vessels

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## Abstract

Realizing Autonomy or remote controlled Inland Vessels can help to maintain waterway-based transport and solve essential problems like labor shortage. Autonomous as well as assisted operation depend on effective sensors, reliable measurements, as well as suitable filters in combination with Machine Learning-based approaches to sense and perceive the environment in all situations. The state-of-the-art is providing diverse approaches to solve problems like localization, object detection, tracking, as well as behavioral prediction for humans and human-guided vessels.

The contribution reports about recent results from the AutoBin and FernBin projects mainly related to questions realizing autonomy, supervising remotely controlled vessels, as well as predicting the intention of encountering ships. The safety and reliability of established approaches will be addressed with real examples from the above mentioned research projects.

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