

## Design of an Autonomous Transport System for Coastal Areas

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**ABSTRACT:** The article presents a project of an autonomous transport system that can be deployed in coastal waters, bays or between islands. Presented solutions and development trends in the transport of autonomous and unmanned units (ghost ships) are presented. The structure of the control system of autonomous units is discussed together with the presentation of applied solutions in the field of artificial intelligence. The paper presents the concept of a transport system consisting of autonomous electric powered vessels designed to carry passengers, bikes, mopeds, motorcycles or passenger cars. The transport task is to be implemented in an optimal way, that is, most economically and at the same time as safe as possible. For this reason, the structure of the electric propulsion system that can be found on such units is shown. The results of simulation studies of autonomous system operation using simulator of marine navigational environment are presented.

### 1 INTRODUCTION

The dynamic development of local communities and tourism in coastal regions and inland waterways creates the need for new forms and functions of transportation. Solutions for transferring road transport to rail, water or air are sought. One of the many ways of reducing road and urban congestion is the possibility of transferring wheeled vehicles to water. The use of this means of transport is all the more conducive when the shape of the area around the water reservoir allows reducing the distance between the transport points. Examples of such activities are the initiative of many local authorities seeking to launch water trams between the most frequented places. Waterway functions can be filled in ad hoc, using existing conventional manned units, or by undertaking long-term planning, taking into account functionality and reducing negative environmental impact while maintaining maximum

safety standards and low operating costs, by deploying fully autonomous units.

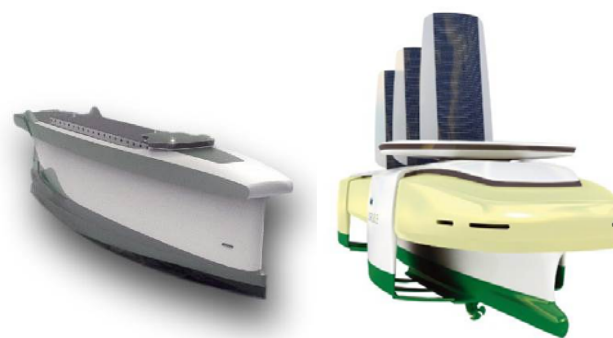


Figure 1. Ecological conceptual models Vindskip and E/V Orcele [1].

It also important to pay attention to the designed units, so they emit the minimal pollution into the environment. For this reason, engineered solutions

include engines fed with gaseous fuels, application of sails, changing propulsion from gasoline/diesel to electric power derived from photovoltaic panels or hydrogen fuel cells [1-6].



Figure 2. Wind Challenger Project [2,3].



Figure 3. LNG Fueled Container Ship by Kawasaki H.I. [4].

There are also ships that use Flettner's aerodynamic rotor with Magnus effect to support the classical propulsion [5,6].



Figure 4. Viking Grace with one Norse-power Rotor Sail [5].

In order to reduce losses associated with motion, structures are designed, whose aerodynamic and hydrodynamic resistance to the hull of the ship in relation to its parts above and below the water, as well as the shape of the propulsors, are the smallest.



Figure 5. E-Ship1 with four Rotor Sail [6].

With the possibility of developing services with autonomous units, one can extend the range of services offered by transporting passengers, goods and vehicles not only to the locations defined by the timetable, but to each of the transshipment points in the area. In addition, autonomous units can be used to collect pollutants and flotsam in coastal and inland waters, as well as around ports and marinas.

At the moment, two basic concepts regarding the use of unmanned ships can be found. The first is based on the ability to remotely navigate through remote communications and camera systems, and the second employs artificial intelligence-based approach to autonomous vessel management without the need for remote operator supervision. Examples of this type of structural design can be found in the Rolls-Royce project proposals for carriers using seagoing ship hulls capable of traveling long distances between ports [7].



Figure 6. Drone Cargo Ship by Rollce-Royce [7].

Another proposal from the consortium of Massachusetts Institute of Technology (MIT), Delft University of Technology (TUD) and Wageningen University and Research (WUR) [8], is the urban water transport concept for cities with access to a large waterway network, such as: Venice, Amsterdam, Rotterdam, Bruges, Stockholm, Bangkok, Suzhou, El Gouna or St. Petersburg.



Figure 7. AMS ROBOAT Q&A [8].

In turn, Kongsberg intends to launch a fully automatic ferry for passenger carriage on a fixed route around Trondheim [9].



Figure 8. Conceptual model of a passenger-cargo ferry by Kongsberg [9].

In this paper, the author presents the concept of coastal water transport organization using small autonomous ecological passenger and passenger transport vehicles.

## 2 STRUCTURE OF AUTONOMOUS TRANSPORT SYSTEM FOR COASTAL AREAS [1-7]

In the last decades, many artificial intelligence methods and algorithms used to support navigational decisions in various DSS systems have been found in world literature [10-25]. Part of the presented methods and algorithms after some modifications are suitable for use in the management of autonomous maritime units.

For steering autonomous units in coastal and inland waters, the author proposes to use an agent system [23-25]. For the first time, the agent system was proposed to direct vessel traffic in 2007 [23]. The agent system consists of an IT agent platform where agents are deployed to perform specific tasks. Agent platforms are installed on computers that control autonomous units and shore stations.

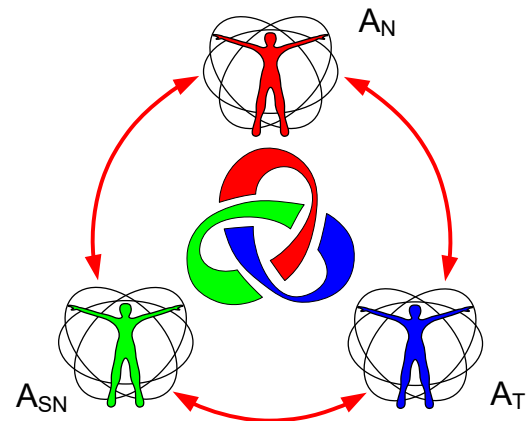


Figure 9. Structure of the platform of the agent system.

The single agent platform consists of three agents: AT - trajectory agent, ASN - navigational agent, and AN - negotiation agent. The task of the trajectory agent AT is to determine the route of the autonomous unit, based on the information provided by the navigation agent from the shore station. At the same time, the trajectory agent is responsible for correcting a given route change in the event of a collision hazard (other units moving in a given area and navigational limits). The trajectory agent is also responsible for precise steering of the autonomous unit, including precise mooring, as well as departure from the wharf. The role of the ASN is to collect information about the current navigational situation around the ship and its in-depth analysis of collision hazards with dynamic objects as well as static objects, which are mostly technical facilities of the autonomous community harbors. Geographic information of the navigational environment in which the autonomous unit moves is mainly provided by the ECDIS in combination with the LIDAR sensor system or optionally video cameras. The task of the AN negotiator is to negotiate with other agents located on the platforms of the autonomous coastal and inland transport system. For this purpose, the negotiating agent may interact with agents located on the agents' platforms of other autonomous entities, but also receive and transmit information from agents located at the shore stations. Thanks to such a system structure, it is possible to transfer information between autonomous units operating in a given watercourse to avoid collisions, but also to disseminate information related to dynamically emerging threats to traffic safety.

The configuration and tasks of the agent platform located on the shore station are slightly different than the agent platform located on autonomous units. Similar to the structure of an autonomous agent platform, the agent platform of the shore station consists of three agents: AC - a communications agent, an ASN - a navigation agent and an AN - negotiator agent.

The task of the Coast Communications Agent is to handle customer orders. AC analyzes orders submitted by stand-alone clients and users and transfers coordinates to AN's Coastal Agent platform negotiator, which is responsible for transferring the geographic coordinates of the point of taking data to a specific standalone unit with the type of execution order - passenger or passenger transport. The AN

negotiator will also exchange information related to the technical condition of autonomous units (fuel quantity, battery charge) in addition to the navigation information provided by the tank. The negotiating agent has a higher decision factor from negotiation agents located on autonomous units. Owing to this property, shore station negotiation agencies can provide commands for the organization of traffic to a given trajectory agent on a platform that is located on autonomous agent platforms [24].

In order to use an autonomous watercraft unit, the user / client must log on to the user database via the web site. Then the user must send an SMS message from the registered telephone number indicating the location he / she would like to use, the start date of the transport, the mode of transport (passenger transport or vehicle transport) and the destination. In return, the user will receive information about the confirmation of selected booking parameters, optionally, the necessities to make changes to the reservation (e.g., information for the user on inability to land the vehicle at the specified location) or the nearest possible date of the transport order. Upon arrival at the place of boarding, the user confirms his arrival by entering the code on the touch panel mounted on board the craft. The user, depending on the transport order, will be informed through the interactive communication interface about the steps he / she should take to safely commence the journey. This is particularly important when choosing the transportation option of a passenger vehicle and the related loading and securing of the vehicle.

Autonomous vehicle control is performed automatically according to the user's destination or fixed route. When ordering a transport by the autonomous craft, it is possible to select specific locations in a given area, or make selection a touristic or scenic route.

The task of the agent system is to direct the autonomous units to the user pickup points in a timely fashion so that the waiting time is as short as possible.

The structure of the agent system controlling the movement of autonomous, ecological units is presented in Figure 10.

Coastal waterborne transport using small autonomous ecological units can be carried out using digital VHF radio, GPRS and AIS.

The task of the agent system is to automatically and autonomously conduct the transport on a given watercourse. It was necessary to develop a way of communicating between agents operating within the agent platform as well as the way of exchanging data between agent platforms occurring throughout the system. Agent actions are characterized by the ability to make autonomous decisions without the need for operator intervention. Agents have the ability to exchange information with the operator, but they may also attempt to negotiate their maneuvers with navigators of other units operating in that particular area. Agents also have the ability to communicate with other agents working within a single platform and the entire agent system so that dynamic changes in the navigational environment are properly interpreted and optimal decisions are made on them.

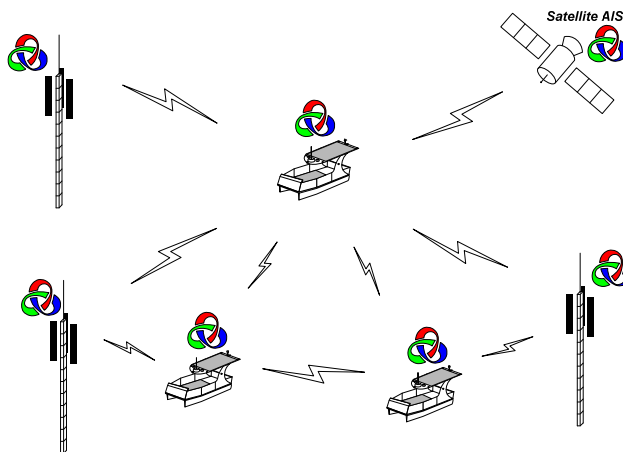


Figure 10. Structure of the agent system controlling the movement of autonomous, ecological units.

### 3 SEA AUTONOMOUS SHUTTLE

For a coastal waterway system using small autonomous ecological passenger, bicycle, mopeds, motorcycles or passenger vehicles, passengers must use adequately equipped vessels like the Sea Autonomous Shuttle (SAS). The structure of the autonomous equipment of the ecological unit is shown in Figure 11.

SAS operation is based on the information provided by the devices and systems installed on board the unit as well as transmitted by radio from shore stations. Operation of the autonomous unit is mainly based on data received from the GPS / GLONASS / GALILEO, AIS, radar, ARPA, anemometer, log, echo sounder and electronic mapping system. Additionally, in particular during mooring, signals from the LIDAR sensor system or optional video camera system are used. After defining a destination for SAS, the control system starts the designated route. The route is determined based on the geographical coordinates of the current position of the SAS unit and the destination. Using the technique of evolutionary algorithms [24], the route for the autonomous vessel is determined. The correct route is taken care of by the AT trajectory agent.

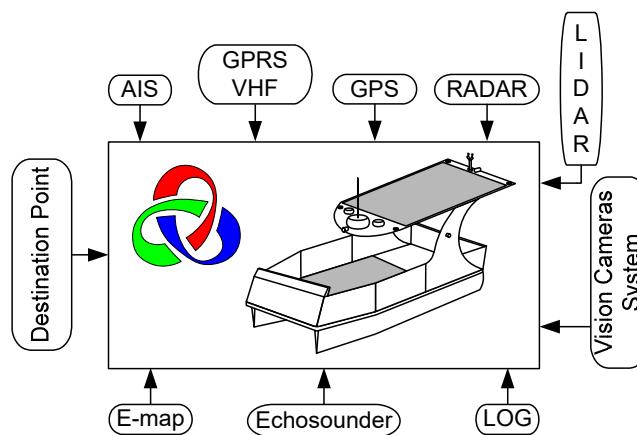


Figure 11. Structure of the autonomous vessel equipment.

When a collision risk for the vessel is detected, the navigation situation is analyzed and appropriate action is taken, depending on its level of security. These actions include negotiating with encountered units to determine the optimal route for the transition. When negotiating is impossible, an optimal route for a particular navigation situation is determined or an anti-collision maneuver is determined. Then the process of automatic control after the route of the transition is carried out. This process is carried out by the trajectory agent, which also includes the precise control of the autonomous unit when departing from the berth, mooring and maneuvering in narrow passages. These actions are possible with information from the positioning system, the radar system, and in particular the LIDAR sensor system mounted in the corner of the autonomous vessel or optionally of the video camera system. The data received is appropriately transformed so that the algorithm that determines the ship's route and the precise control of following that route can be processed safely. 3D objects identified in the maritime navigation area by a radar, AIS, LIDAR sensor system or optional video camera system are brought to the 2D plane. As a result, all objects projected on a 2D plane are collision hazards for a ship on which a standalone agent platform is installed. Depending on the motion parameters, identified objects can be dynamic or static. For such specific navigational limits, artificial intelligence methods can be used to determine the optimal route of transitions. Evolutionary algorithms are used in the described system of directing the movement of autonomous crafts in coastal and inland waters to determine optimal transition routes.

The autonomous, ecological SAS craft is equipped with a 5kW electric drive powered by a battery pack. In addition, the autonomous unit for precise control uses two thrusters: bow and stern thruster, with power of 1kW each. The energy stored in the battery pack allows the unit to be operated for about 10 hours. In addition, the battery pack can be powered by an auxiliary generator, which allows it to operate when the energy in the main battery pack is consumed. On the roof of the unit, and on the front of the deck, there are photovoltaic panel units which supply electricity directly to an inverter that powers an electric motor or to the battery pack. The unit is also equipped with connectors to automatically connect to the battery charger installed on shore.

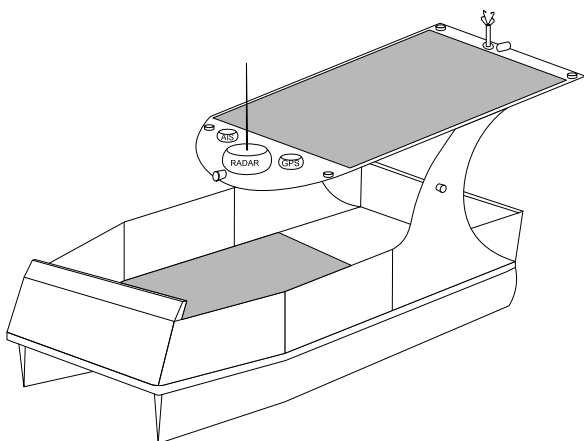


Figure 12. Appearance of an exemplary autonomous unit with positioning sensors.

#### 4 VERIFICATION OF THE AUTONOMOUS TRANSPORT SYSTEM FOR COASTAL AREAS

A network simulator of the navigational navigation environment was used to verify the operation of the coastal waterway system using small autonomous ecological units. This simulator has the ability to execute navigational scenarios along with the parameters of the watercourse in which they operate. The simulator consists of a central unit - the server on which the navigation environment is modeled and local stations emulating single autonomous units. The navigational scenarios concerned the verification of the system in conflict situations between autonomous entities. The mathematical model of the developed model of the autonomous unit includes the dynamic properties of the hull, the main propulsion consisting of a single fixed pitch propeller, a fin rudder and two transverse thrusters: fore and aft. The model of ship dynamics also takes into account the influence of hydrometeorological disturbances in the form of wind, wave and sea currents, as well as changes in vessel dynamics caused by the shallow-water effect [25].

Verification of the motion control system of autonomous units in coastal and inland waters was based on a series of computer simulations using the simulator of the navigational navigation environment. Below is an example of a navigational situation illustrating the movement of autonomous units in the waters of the Gdańsk Bay (Figure 13).

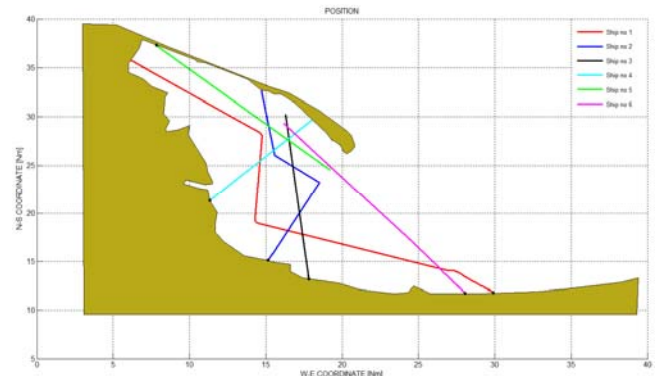


Figure 13. Navigation situation depicting the movement of autonomous units in the waters of the Gdańsk Bay.

Agent platforms were launched on all units involved in the imaged situation. Out of 6 units, 4 were equipped with an agent system. The motion parameters and weather conditions parameters are presented in the Figure 14.

The routes of Unit 1 and 2 are designed to transport passengers from boarding place to destination place and at the same time to take advantage of the tourist mode so that the individual route can be planned to include areas with interesting places or views of natural landmarks. Based on the simulations, it can be concluded that the system has correctly implemented the control process between the starting point and the target point. In the event of a collision risk, in this case exceeding the Closest Point of Approach distance (CPA), the system correctly corrected the current route. By using an agent system to control autonomous units, it is possible to set smaller values for the smallest CPA

distance parameter, given that the individual agent platforms have precise information about the route parameters of other units that cooperate within the system.

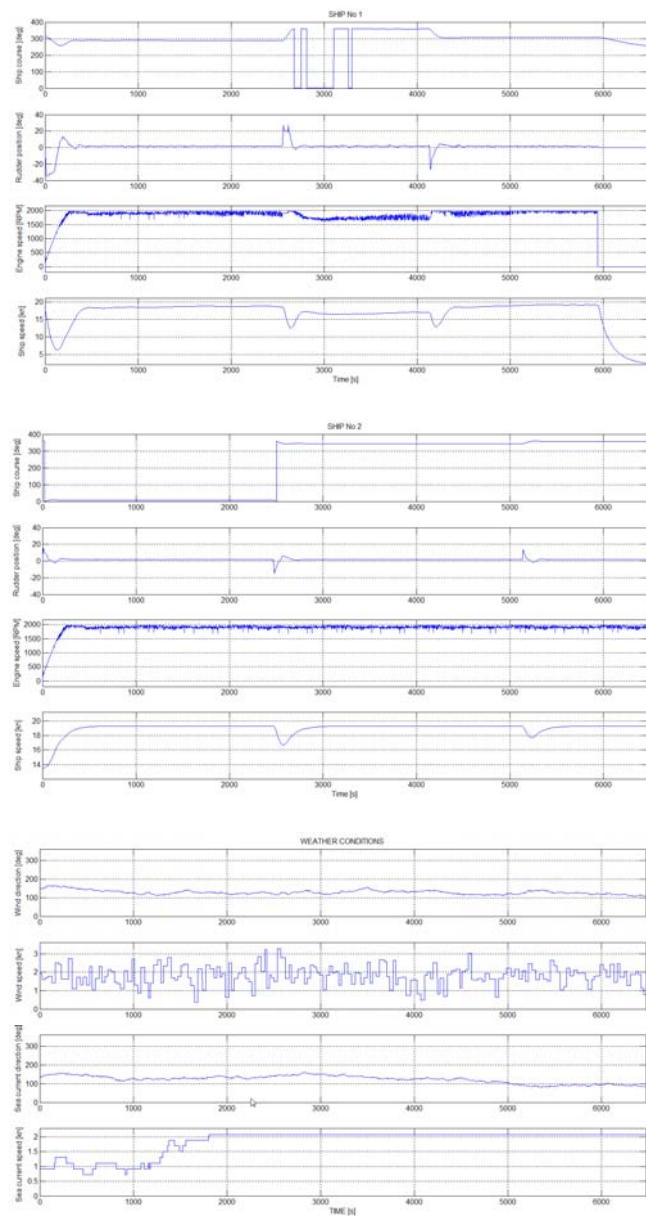
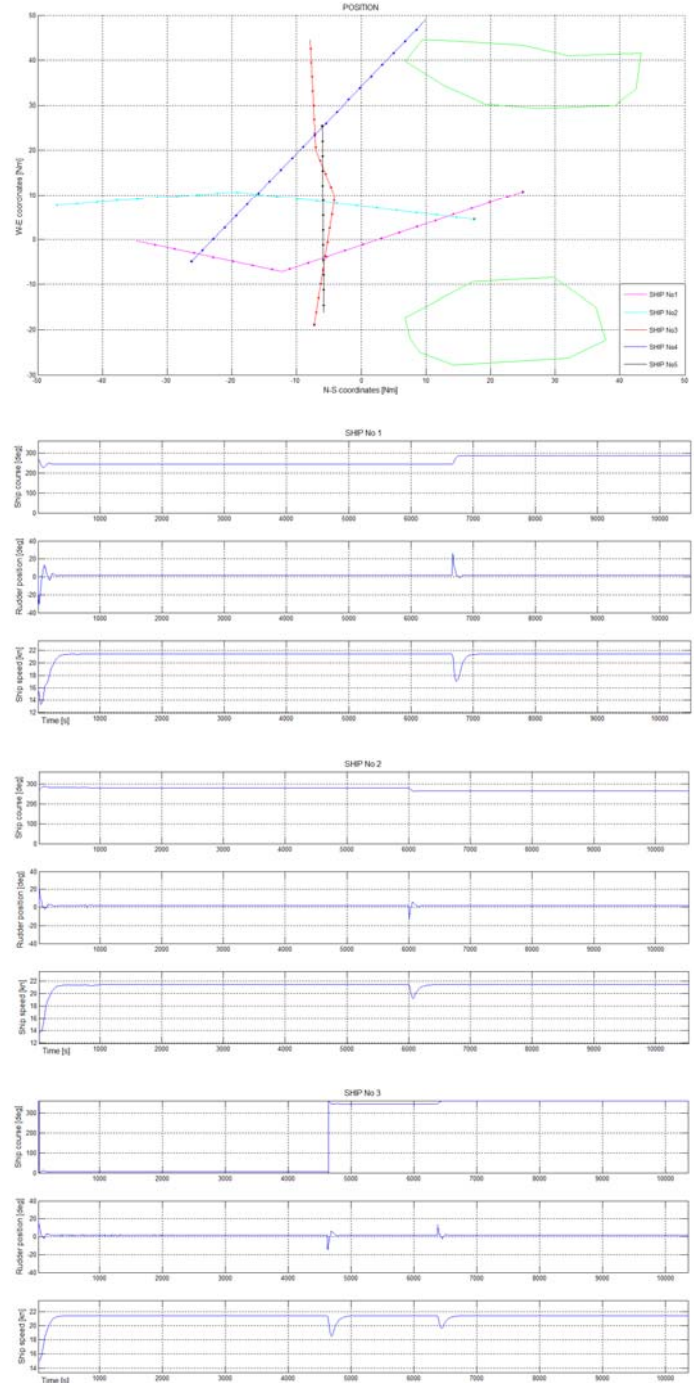


Figure 14. Motion parameters of selected autonomous units and description of meteorological conditions.

Defining smaller CPA values has a direct impact on reducing the size of areas around the affected units in a given area, the violation of which results in an increased risk to shipping safety. Defined areas are taken into account by a specialized evolutionary algorithm [24] as one of the artificial intelligence methods used by the AT agent trajectory agent to determine the optimal route for the current navigational conditions. This gives us the ability to designate the shortest and the most secure passage route. Unfortunately, this comfort is not guaranteed by an agent system when a vessel is moving in a given area, and is not possible to establish communication with it and thus negotiation by AN negotiator is impossible. In this case, the agent system will perform the route determination process for the standalone unit based on the information provided by the radar, LIDAR and AIS systems, taking into

account the International Maritime Organization's COLREGs regulations.

In the next navigational situation, 5 autonomous units equipped with an agent system were involved. The motion parameters and weather conditions parameters are presented in Figure 15. Thanks to the cooperation of agents installed on the agent platforms, the optimal operation of the autonomous units from the starting point to the destination was achieved. This gives one the potential to reduce the operating costs by saving time and reducing energy consumption.



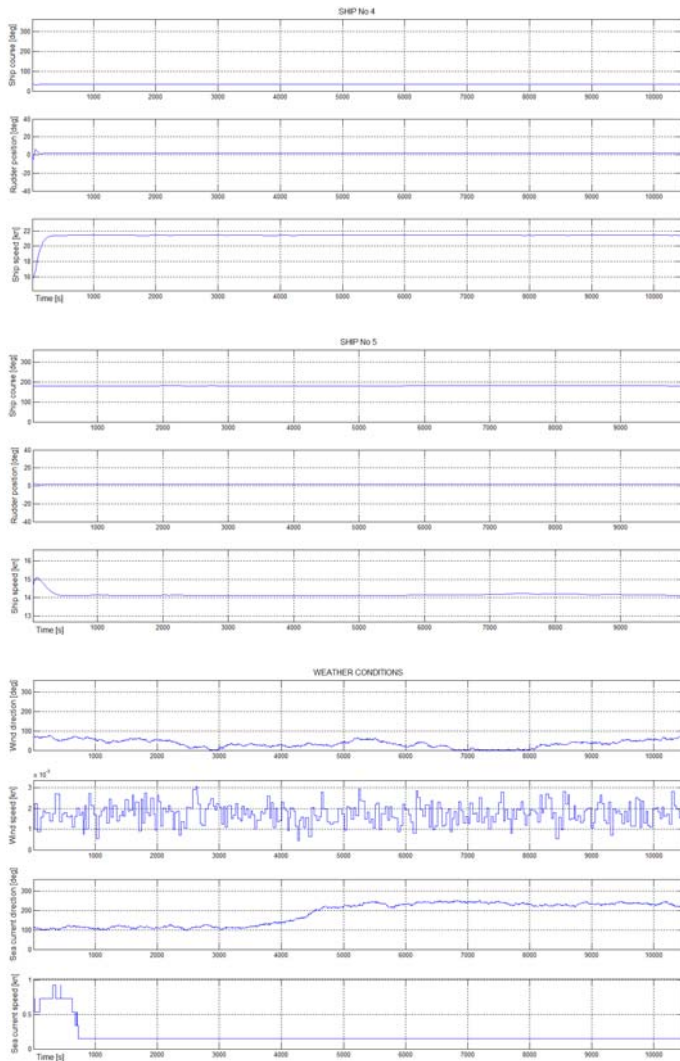


Figure 15. Motion parameters of selected autonomous units and description of meteorological conditions.

## 5 CONCLUSIONS

- Simulation studies have shown that the use of an agent system to manage an autonomous coastal water transport system using small ecological units has positive effects.
- The use of the system in practice enhances the safety of the users of the area, including rescue and exploration operations where autonomous entities can participate by using the video camera system.
- Research has shown that even when a single autonomous unit loses contact with a shore station, it is possible for it to operate autonomously in the navigation environment. Using an agent system reduces the risk of collisions with other objects, raising the level of security in a given area.
- The use of autonomous units opens up new opportunities for tourism and business services.
- The main obstacle to the use of autonomous units are legal regulations and issues of legal and financial liability in the event of an accident.
- The use of fully automated autonomous units increases the level of navigational safety and the efficiency of coastal and inland transport. The

algorithms used to determine the route of travel fully respect the rules of the International Maritime Organization COLREGs, which cannot be said of many navigators.

The use of autonomous units introduces new possibilities for ship design in the future, where crew social rooms can be repurposed to handle more cargo instead.

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