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Possibilities of autonomous means of sea transport

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Abstract

In recent years, there has been an intensification of work on the autonomy of means of transport, which also applies to ships. Modern ships are already equipped with crew decision support systems and numerous diagnostic systems. Increasingly more systems are installed on ships that can operate without human integration. This situation leads to the development and use of fully autonomous ships. This overview publication briefly describes the main features of the construction and operation of autonomous ships, including some examples of structures already demonstrated in recent years. In summary, the author presents comments that provide a contribution to the discussion on the autonomy of means of maritime transport.

Introduction

A characteristic feature of the new industrial revolution is the gradual replacement of humans with robots. We are able to increasingly automate complicated activities, so various professions have begun to disappear and progressively more are expected to follow. Not so long ago, it might have seemed that the profession of a driver would not be endangered for a significant amount of time. However, autonomous vehicles that drive themselves may soon become quite commonplace. Thus, the development of autonomous vehicles is undoubtedly a trend in the transport industry.

Probably within a few years, the first autonomous, driverless vehicles will appear on the roads. From a technical point of view, it is already possible today – such attempts are already made, often with success. Moreover, airplanes have been flying over our heads for years – including powerful passenger machines, which for most of the routes are driven by autopilot. But how is it to be made really safe, at all stages of the journey, for all road users? Probably this aspect will decide upon the success of the project or its rejection (Porathe, 2016; Schwithal et al., 2017; Rødseth, Nordahl & Hoem, 2018; Pepliński, 2019; Wróbel, Krata & Montewka, 2019). There still remains the difficulty that more urgent civilization and scientific problems need to be solved, but who knows, maybe autonomous vehicles will allow us to take better care of these issues and not waste valuable time on human control of machines that monotonously travel hundreds and thousands of kilometers.

The article offers a review on such concepts. Its purpose is to present trends in the development of autonomous means of transport and, against this background, the means of sea transport. It acts as a contribution to the discussion on the future of the autonomy of the means of maritime transport.

The specificity of the structure and development of autonomous means of transport

It seems improbable, but the first works on the autonomy of means of transport, on self-propelled vehicles, were carried out as early as the 15th–16th centuries. By Roberto Valturio (1405–1475), who developed the design of a wind-powered vehicle, and Leonardo da Vinci (1452–1519) (Porathe, 2016) (Figure 1). In 1600, two-masted wind-powered vehicles – sailboats (Porathe, 2016) – constructed by the Dutch engineer Simon Stevin (1548–1620) (Rødseth, Nordahl & Hoem, 2018), were in operation in the Netherlands. In his work "Astronomia Europea", the Belgian Jesuit missionary to China, Ferdinand Verbiest (1623–1688), described a model of a steam-driven vehicle (Pepliński, 2019).

Figure 1. Self-propelled vehicle built according to the design of Leonardo da Vinci (Porathe, 2016)

The first constructor of a self-propelled wheeled vehicle capable of transporting people – a prototype of a car – is considered to be the French engineer Nicolas Joseph Cugnot (1725–1804), who built steam-powered vehicles to act as an artillery tractor for the French army – the first was built around 1765 and another around 1770 (Schwithal et al., 2017). The following years, especially in the nineteenth century and the twentieth century, brought many achievements by engineers and inventors, laying the foundations for today's advances in the field of autonomous vehicles. The almost universal introduction of electric drives in vehicles enabled this development.

The British technology company Starship Technologies has created an autonomous ground robot that delivers shipments to customers. Now the Swiss Post uses these vehicles during its operations.

The Starship vehicle can transport purchases that weigh approximately 15 kilograms. It moves at a speed of 6 km/h and it is equipped with electronics that enable autonomous driving (Figure 2). The

Figure 2. Autonomous courier vehicle

robot works autonomously, but its actions are monitored by the operator. If the vehicle encounters any obstacles, the operator will take control of it. The equipment also has a microphone and loudspeaker, thanks to which communication with passers-by or customers is possible. The chamber holding the parcels is properly secured, and access to it can only be obtained by the addressee who uses a special application.

Autonomous courier drones are being introduced on the streets of Bern and two other Swiss streets. For drones manufactured by Starship Technologies, it will not be the first time that it is taken to the streets. Previously, the drone on wheels was tested in London and the United States. However, Starship autonomous couriers will not be a solution on a large scale – their task will be to carry out deliveries only over short distances, so that parcels reach customers faster. In addition, they deliver only certain types of shipments. It is primarily intended for food and medicines, i.e. assortments that should be at the destination within an hour.

There have already been attempts at autonomous vehicles without a driver, often with success. For years, airplanes have been flying over our heads – including powerful passenger machines, which are driven most of the routes by autopilot. Soon Singaporeans will be able to take advantage of self-driving taxis. The idea of autonomous vehicles is not new,

Figure 3. Automated taxis by "nuTonomy"

Figure 4. Computer-controlled truck

but it was the company nuTonomy who used it to create the world's first fleet of fully automated taxis (Figure 3).

Last year, Daimler obtained approval for a computer-controlled truck (Figure 4). Work on autonomous, i.e. computer-controlled vehicle systems, has been underway for over 30 years. The first autonomous transport system was introduced on the Kobe metro line in Japan in 1981. Today there are over 1000 km of autonomous metro lines in the world, most of them reside in France. Driverless vehicles also run on the lines of airport railways or monorail lines. There is no such system in operation in Poland yet, but the Warsaw metro is technically prepared for driving without a driver. The rules and the mentality of people who are afraid to board the train without a driver remain an obstacle. For the metro network, the introduction of an autonomous system allows an increase in the frequency of vehicle journeys, shortens the train conversion time, and reduces the costs of the system's operation. Both passenger and freight railways are also preparing to introduce driverless vehicle traffic. Currently, autonomous trains can only operate on separate lines, such as the over 100 km long Australian freight line located in a remote area.

A willingness to introduce autonomous vehicles is declared by German Railways and the French state railways, SNCF. The first step towards autonomous railways is the implementation of the ERTMS system that enables vehicle tracking and the receiving of signals from the railroad. However, this solution alone is not enough. In order for the train to run without the participation of the driver, it is necessary to equip it with mechanisms that receive additional information. For instance, the autonomous control system needs information about the starting and braking point, which side the doors open, the tracking of the track situation, and much more. The current TSI provisions allow autonomous vehicles to run only on segregated lines. In turn, Polish regulations require that each rail vehicle has at least one driver. However, this situation may change in future. It is assumed that future vehicles will be equipped with automatic train control systems, and the next step will be to train personnel to take control of the vehicle and stop it in the event of a breakdown. The initial vision of autonomous road transport on a mass scale was presented at the World Fair in 1939, by General Motors, at an exhibition it organized called "Futurama". For several years, the Swedish company Einride has been working on a truck in which not only is there no steering wheel, but no driver's cabin at all.

The aviation industry proves that the construction of a means of transport capable to some degree of self-steering does not require the use of computers at all. This is interesting because aviation appeared later than the automotive industry, but the first autopilot, i.e. a system capable of independent flight control, was created much earlier, before anyone in the automotive industry even thought about autonomy. The world's first aviation autopilot was created just 9 years after the success of the Wright brothers, 105 years ago. The inventor of this first solution was the American pilot and constructor Lawrence Sperry. He had a good teacher, his father – Elmer Ambrose Sperry – was a recognized inventor and the holder of over 400 patents. The key invention that helped Sperry develop the first ever aviation autopilot was the gyro compass, invented by his father in 1910, as well as the gyro autopilot used in maritime transport. The mechanism he developed was relatively simple – it combined a gyroscopic compass with hydraulically controlled ailerons and aircraft controls. This analog system passed the test and for many years it has functioned, in a changed form, in the aviation industry. However, today, when we talk about autonomy in transport, most often in cars, we do not imagine any solution that is created in isolation from computers and digital technologies.

There is also increasing talk about the production of vehicles that could drive and fly. Engaged in the work on flying cars are, among others, Larry Page from Google, financing startups Kitty Hawk, and ZeeAero. Terrafugia is already collecting orders for this type of vehicle and promises to deliver the machines to the first customers within the next five years.

Airbus also wants to contribute to the creation of a new transport segment, although the Vahana is something different compared to the flying car that competing companies are working on (Figure 5). Airbus's vision is to create a service similar to Uber – except that instead of land transport, it focuses on air

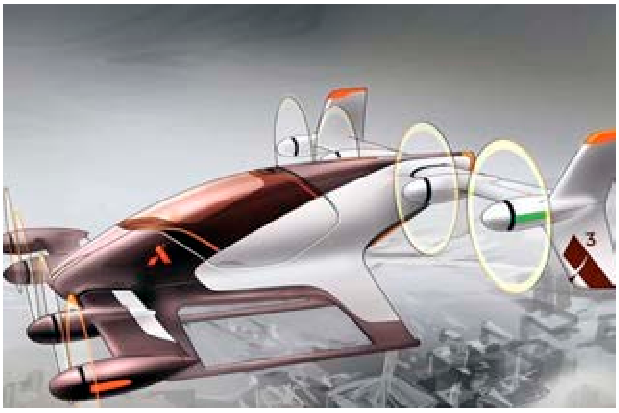

Figure 5. Vahana Airbus (Rødseth, Nordahl & Hoem, 2018)

use. The customer will be able to order Vahana using a smartphone application, select the destination and be transported there. Interestingly, the service would be cheap – using a flight through the city will probably cost as much as a traditional taxi ride. According to the current project, only one person will be on board the Vahana, and its safety is to be supervised by a precise system that analyzes land and air data on an ongoing basis. In case of trouble, a parachute will be activated, which will safely bring the vehicle and the passenger to the ground. The issues of safety and legal regulations are one of the greatest challenges in this type of undertaking. Airbus has a few more years to consider and implement them.

SCNF, the French railway company responsible for managing rail services, announced that it is implementing a program to run autonomous trains on TGV high-speed lines. The tests are expected to start in 2019 and, in 2023, the first of them will be on the tracks to serve passengers. Autonomous systems will be built into TGV trains running today. They will consist of external sensors that will initiate automatic braking upon the detection of obstacles on the tracks. French railways estimate that, thanks to the use of an autonomous system, they will save time and, thus, it will be possible to run 25 percent more journeys on the same lines. The first to be served will be connections between Paris and cities in the southeast of France. At the beginning, the trains will still have a crew, because the system will require both control and error elimination on a regular basis. But when everything is checked and verified, the trains will start running without human supervision (Schwithal et al., 2017; Zhang et al., 2019).

Of course, France is not the only country to embark on the path of autonomous rail transport. Already, last year, the German State Railways (Deutsche Bahn) announced that they had launched a pilot project to examine how driverless trains perform. The tests occur at the Erzgebirgsbahn technical training ground in Saxony. The CEO of DB Ruediger Grube announced that he expects some sections of the railway network to be fully autonomous in around 2021–2022 (Figure 6). In addition, Japanese carrier JR East has announced a series of tests of autonomous high-speed trains. Trials under the Change 2027 program will be carried out in October and November 2021. Such trains are to be added to the Shinkansen super-fast railway network in future. This Japanese carrier, which operates on all the lines of the Shinkansen network north of Tokyo, has announced a series of tests involving a 12-car, autonomous high-speed train (Figure 7).

They will run to the northernmost section of the Joetsu Line between Niigata and Higashi-Niigata stations, which is 5.75 kilometers long and currently not used for commercial purposes. The modified E7 series will be used in the testing. These tests are

Figure 6. French SNCF trains that are to become autonomous (Wróbel, Krata & Montewka, 2019)

Figure 7. The super-fast Shinkansen railway line (Rødseth, Nordahl & Hoem, 2018)

aimed at collecting data on the autonomous movement of this type of trains. JR East explains that during the tests, aspects of their functioning will be assessed, such as automatic starting of the train, operation of control devices (both on-board and those located along the route), speed of the train, the effectiveness of stopping it in a specific place, or the possibility of remote emergency stopping of the train. JR East will also test high-definition video transmission capabilities using the 5G infrastructure that Japanese high-speed trains are likely to use in the future.

Autonomization of means of sea transport

Until now, cars, trains, and then planes have been at the center of discussions about greener transport. Sea transport was almost completely neglected. This, however, is changing. For example, the Norwegian company Yara International have shown the world a project on an electrically powered container ship. An autonomous ship is a unit controlled and supervised by an on-board computer system. No crew on board is required to operate it. Experts estimate that the first unmanned ships will be container ships, delivery tankers, short-haul passenger and car ferries, research units, or port and technical ships. It is expected that unmanned ships will also be used by the navy. The use of unmanned ships brings many benefits. They will be more ecological – powered by electricity – so that they will be significantly reduced emission of pollutants into the atmosphere from maritime transport. By using unmanned vessels, shipowners will significantly reduce the operating costs related to employment and maintenance of the crew on the ship (Gabrys, Leiviska & Strackeljan, 2005; IMO, 2018a, 2018b; Wright, 2019).

The degrees of autonomy according to the International Maritime Organization are:

Category I – unattended operation of the engine for a specified period of time when the ship is full of crew, who can take over the control of the vessel if necessary; automatic systems and decision support systems are installed on the ships.

Category II – remotely operated and manned vessels that may assume control of the vessel's functions and systems.

Category III – remotely operated ships with no crew members on board.

Category IV – ships where all decisions are initiated by computer automation systems that are installed on the ship.

The autonomous navigation system includes:

1. Data for autonomous navigation
   - Camera systems
   - Height and distance sensors
   - Sonar systems
   - Anti-collision systems
   - Weather sensors
   - Other information
2. Integrated automation and remote-control system
   - Bridge systems
     - Radars
     - GPS, GLONAS, Galileo, and BDSony
     - Gyrocompass
     - Echo sounder
     - LOG, AIS, ECDIS, and LRiT
   - Gym control systems
     - Power plant
     - Fuel, lubrication, and compressed air systems
     - Sea and fresh water, bilge, and ballast systems
     - Other.

To ensure the reliability and efficient functioning of the Autonomous Navigation System, the computer equipment will be triple redundant with the possibility of its repair and testing during operation, and non-working teams will be in active reserve. Elements and sensors of the system will also be redundant, and they will have self-control functions with the detection and isolation of failure components. The components of the Autonomous Navigation System will be connected by a redundant fiber-optic network via "Computer Network Nodes" (NDU). Specific devices for an autonomous vessel will be connected to the "Local Stations (FS)" of the Autonomous Navigation System, e.g.:

- cameras of a computer imaging system for the environment with threat detection;

- sonar sensors for sea state, wave height, and obstacle detection on and under water;
- unit position control systems including front/rear undulation (Surge), sideways inclination (Sway), longitudinal inclination (Pitch), transverse inclination (Roll), and up/down heave;
- maritime collision avoidance systems with distance determination to other ships, and objects equipped with redundant infrared and dark imaging cameras, etc.

The construction and operation of autonomous ships in the era of coronavirus will additionally provide better protection against the spread of the virus. These times will not only affect the way of life of mankind, but also, for example, maritime transport and offshore oil and gas extraction systems. Currently built units are increasingly automated. Ships are often equipped with crew decision support systems and diagnostic systems in the installed devices. Increasingly more systems installed on ships and offshore units can work without human integration. Such a situation in the future will lead to the development and use of fully autonomous ships. Several prototype designs of autonomous ships are shown below (figures 8–11), (Kongsberg, 2017; IMO, 2018b; McAndrew, 2019).

Wärtsilä used a standard satellite link to remotely operate the DP (Dynamic Positioning) system of the Highland Chieftain platform supplier (built at Repair Shipbuilding in 2013, one of a series of three PSV twin vessels for Gulfmark Offshore). The vessel, operating off Aberdeen (on the coast of Scotland) at a 4000-tonne platform, was steered 8000 km from San Diego, California (Offshore Energy, 2018).

An American company has just announced that it is joining a global consortium, led by ProMare, which has the potential to revolutionize marine research. The Mayflower Autonomous Ship (MAS) is to be the first unmanned and fully autonomous ship to be used in maritime research.

Conclusions

At present, the development of autonomous ships is not coordinated. A natural way to coordinate the development of autonomous ships would be to implement international law on technical requirements and the insurance of ships and the cargo that they carry. The International Maritime Organization (IMO) could implement the requirements for autonomous ships. At present, mainly classification societies are working on defining the requirements for autonomous ships. The cost-benefit analysis of

Figure 8. Project of the first unmanned container ship, in which 100% of the electricity is from the Norwegian transport company Yara (IMO, 2018b)

Figure 9. Remote maneuvering of the 28-meter tugboat Svitzer Hermod in the Copenhagen port in 2017 (Kongsberg, 2017)

Figure 10. Prototype of the Kongsberg Maritime electric container ship (McAndrew, 2019)

Figure 11. Mayflower Autonomous Ship (McAndrew, 2019)

autonomous ships' operation shows the greatest savings for unmanned voyages on long ocean voyages. Sailing without a crew in the Atlantic, Pacific, or Indian Oceans would allow for significant savings on crew costs. The difficult and risky conditions for autonomous shipping in small areas, such as the Baltic Sea, should also be considered. According to experts on the subject, the construction and operation of periodically autonomous ships, with full autonomy during ocean cruises, should be considered.

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