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Increasing Navigation Safety by Introducing the Modern DunaInfoControl Control System

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Abstract

The study presents a development proposal coordinated by the Hungarian Academy of Engineering (MMA) for intelligent navigation management on the Danube. We analyse the introduction of a security-enhancing central control system based on the IDM model. The publication reviews the main issues related to navigation safety in Hungary. Without claiming to be exhaustive, in the field of water transport control theory and practical applications, important players include HUN-REN SZTAKI, Budapest University of Technology and Economics, Széchenyi István University, HungaroControl Zrt. and the Water Police. This development requires combining modern control theory and a high-capacity 5G network. The program proposes the implementation of intelligent control in the first phase in the Budapest area, between river km 1660 in the north and river km 1633 in the south. This is because accidents much larger than the "Hableány" boat tragedy that occurred in Budapest on the evening of May 29, 2019, at 9:05 p.m., may occur in this section in the future. Consider, for example, the appearance of convoys transporting 6000-8000 tons of dangerous goods on the Danube. These represent a very serious source of danger in the event of collisions with the Budapest bridge piers. The proposal also intends to support the RSOE river IT system (developed by NOVOFER Zrt.), which has been built and operating since the end of 2018.

Keywords

Danube accidents, intelligent control, navigation safety, water transport

1 Introduction

International transport routes within the EU - TEN-T corridors - are receiving priority development. Despite this, numerous and partly avoidable water accidents have occurred on shipping routes. In the 2021-2030 cycle, uniform solutions must be developed to eliminate them. The DNV-GL - one of the largest international ship classification institutes - published a "White Paper" in 2020 entitled "CLOSING THE SAFETY GAP IN AN ERA OF TRANSFORMATION", in which it outlined the main problems related to shipping safety - pointing out that these can only be overcome with a unified concept. The institute, which oversees intensive developments in 100+ countries and plays a leading role not only in shipbuilding and maintenance but also in the application of renewable energies, makes the following statements in its publication:

Based on the forecasts for 2030-2050, the success of all development results is expected to depend on how well it considers the predictable risk factors that may arise from the developments (Péter et al., 2021). Digitalisation and automation mean complex applications that require introducing new methods in the field of operation. For this reason, traditional risk management systems are unsuitable for handling disturbances occurring in these systems; instead, new ones must be developed, taking into account the following aspects, in order to be able to avert disasters based on predictions that threaten safety:

1. In our time, an increased level of safety in shipping can be achieved by involving trained human participants in risk prevention work.
2. Decarbonisation - driven by climate protection - requires the widespread use of renewable fuels, which, in turn, pose new challenges due to the risks arising from their storage. This can only be overcome by new legal and technical regulations.

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3. The regulations required for a carbon-neutral shipping solution - from exploration to end-users - require transparent regulations and a commitment to them, which can only be created by teamwork with collective knowledge and precise implementation.
4. Teamwork with collective commitment requires the availability of knowledge and experience and compliance with and enforcement of the regulations that support it.
5. The development of special competence is characterised by continuous learning, the culture of which can create the necessary knowledge and experience for safe water transport.
6. All shipping organisations must participate in achieving safe and efficient performance, which in turn presupposes an optimised human-technology relationship.
7. The success of the transition depends on the people who will carry out the tasks. Therefore, it is essential to consider what task the employee can be entrusted with. This person must have the creativity, problem-solving, and decision-making skills required by new and safe transport operations.

2 Important and necessary capabilities for navigation systems

2.1 Navigation safety

"Safety" comes from the Latin word "securus", which means a state of being free from worry or fear and refers to the ability to avoid threats. This is a particular concern for navigation systems. In navigation systems, threats are caused by human and technical errors, simultaneous external influences and sudden events. The ability to avoid threats in navigation systems requires that all its components are reliably available and able to cooperate under the current circumstances. In the field of inland navigation safety, e.g., with the introduction of RIS (Directive, 2004), ship captains are given a current and complete overview of the traffic situation. This allows them to make well-informed navigation decisions, which in turn reduces the number of accidents, injuries and fatalities. By establishing the control centre, we can implement comprehensive and transparent information processes and smooth data exchange between all partners involved in the transport chain by developing coordinated interfaces.

2.2 Robust shipping systems

The construction of this system takes a long time and requires complex development. These competencies are developed with practical experience, and the appropriate specifications and standards are also developed to obtain a safe shipping system that has been operating for many years and can handle errors that occur during operation without fundamental changes.

2.3 Flexible shipping systems

A flexible shipping-transport system is a demand-driven transport system (flexible transport systems, demand responsible transport, DRT) that, unlike traditional systems, determines the schedule or the transport route, or both characteristics - depending on the degree of flexibility - according to the current transport needs. The level of service of such systems exceeds that of traditional transport systems. This requires a modern control centre, which is also supported by (Mező, 2019). The control centre meets the information needs of modern supply chain management and allows for optimal use and monitoring of resources. Flexible response becomes possible in the event of any deviation from the original plan (Directive, 2004; van Essen et al., 2019). This allows for a transparent, reliable, flexible and easily accessible mode of transport.

2.4 Ability to continuously improve

In this case, the tasks and mechanisms depend largely on the system's ability to provide feedback on the positive or negative effects of the outcome of events (Péter et al., 2020). The reliability of shipping systems largely depends on their ability to use and incorporate experiences from so-called "creative concerns". In other words, the extent to which the lessons learned from an incident - i.e., the culture of learning - can be used. The digital transition also leads to the achievement of "smart shipping". This concept can also be extended to "sustainability" as it affects climate change. This brings us closer to achieving fossil-free transport. The series of accidents presented in Table 1 caused significant material damages. Unfortunately, 243 people died in these accidents in the event of a collision, which is 96.4% of all accidents. All this justifies further examination of the implementation of intelligent Danube navigation control. This also entails examining and introducing the applicability of IDM models in the modelling stage, considering river traffic.

The following paragraphs present typical accidents in the Danube in Hungary from the 1970s.

09.09.1972. The SIRÁLY-II departed from Vienna to Budapest with 52 passengers. Arriving in the Újpest-Megyer region, it gave a situation report on the radio at 19:00 and then 1-2 minutes later, accompanied by a

Table 1 Danube ship accidents between 1982-2024

Year	Death toll in Danube ship accidents	Number of fatalities in collision accidents on the Danube
2024	6	6
2019	28	28
2016	2	2
2005	1	-
1996	8	-
1991	3	3
1989	200	200
1983	2	2
1982	2	2
Total	254	243
		96.4 %

knocking sound, the ship tilted slightly to the right. At that time, the first stabiliser of the SIRÁLY II collided with an unlit motor tour boat crossing its route at an angle of about 50 degrees, which claimed two lives, among other things, due to poor visibility.

Between 1983 and 2007, 202 people died in shipping accidents on the Hungarian Danube due to collisions, accidents caused by fire, and falls into the water, mostly due to human error.

On 09.05.1983, the SIRÁLY I collided with the corner edge of the rear barge of the Vilnius pusher at a speed of approximately 70 km/h. The barge tore the left side wall of the passenger compartment, and nine seats with passengers were crowded together, causing a leak. Two of the eight watertight air compartments that increase the buoyancy safety of the hull were damaged. The consequence was the death of 2 passengers.

On 09.09.1983, a Romanian excursion boat collided with a Bulgarian pusher convoy, which alone caused 200 deaths on the lower Danube.

In 2007, there was a collision on the M0 ring road, with two deaths.

In 2007, a boat capsized near Soroksár, one dead,

2016 Szigetbecse, people fell from the boat, resulting in one dead.

In 2017, a motorboat crashed into a floating structure, resulting in one death.

05.29.2019. The Hableány cruise ship accident. In this accident, even during bad weather conditions, the risk of an accident could have been significantly reduced with external preventive intervention. However, it was not. Unfortunately, 28 people were killed.

02.12.2021. Barge colliding at the Rákóczi Bridge. According to the information from the Disaster Management Authority, an object heading towards Vác collided with the pillar of the Rákóczi Bridge during a manoeuvre early in the morning, which could only be freed with several days of intervention.

03.16.2021. The Ukrainian ship Chelyabinsk was pushing six barges on the Danube when it collided with a pillar of the Türr István Bridge at Baja, and the connected barges scattered.

05.19.2024. 11:30 A fatal boat accident occurred on the Danube near Verőce, where a hotel ship collided with another small motorboat at night. The accident resulted in 6 fatalities.

12.22.2024. A watercraft consisting of six barges collided with smaller ships and the pier of the Margaret Bridge on the Danube bank, causing significant material damage. There were no reports of personal injuries.

Most fatal accidents can be prevented or avoided with properly regulated procedures, and their severity can be significantly reduced with well-organised rescue.

3 Port supervision and traffic

As a world city, Budapest offers one of the most beautiful panoramas among European cities in terms of coastal traffic and shipping. However, many ports along the shipping route serve passenger transport and can be divided into two categories:

1. International ports with nine berths and occasionally double (triple) ship berths.
2. Public ports, with 29 berths for tourism, which, according to Mahart Passnave data, have the following annual traffic: 3,000 berths serving 130000 passengers.

No other services are provided at the ports besides berthing and logistics services. At the same time, the RIS system is operated by a separate company, where the primary services are cargo shipping and general navigation services, including informing shipowners and providing current water data. The current system cannot provide sufficient security for real-time ship tracking with the AIS system, as neither the deployed devices nor the processing IT system are suitable. The system was only prepared for subsequent ship tracking and cannot be further developed into a preventive solution. It follows that the supervision of daily port traffic in the river section and the supervision of transit shipping traffic must be improved. An additional preventive function is also needed to raise the complex task of traffic management to a higher and safer level than before.

However, the above capabilities are urgently needed, as a significant increase in shipping traffic is expected by 2030.

- A 4-5x increase in cargo shipping is expected, within which container shipping can develop outstandingly. A 10-12% increase in 6-8000-ton convoys and dangerous goods traffic can be expected.
- In passenger shipping, an annual growth of 10-12% is expected for cruise ships operating internationally if the pre-pandemic situation returns.
- We must also consider the start of agglomeration shipping with daily traffic of 20-25000 people and the growth of sports and small boating.

4 Increasing navigation safety

It is important to highlight that navigation routes are standardised by assigning the dimensions of navigational equipment according to the provisions of the AGN Convention.

This is determined in Hungary by Decree No. 57/2011. (XI.22.) of the Ministry of Finance and its Annex 1 (Ministry of National Development (NFM), 2011), according to the AGN Convention's provisions- with the Navigation Regulations' provisions. At the European Union level, the directives regulating safety are the following:

- Directive 2005/44/EC (EP, 2005) on the introduction of RIS,
- Directive 2010/65/EU of the EU Parliament and of the Council (EP, 2010), on the declaration obligation for ships arriving in and departing from ports of the Member States,
- 2015/EC (Dick, 2015), National Single Window Guidelines, EUROPEAN COMMISSION DIRECTORATE-GENERAL FOR MOBILITY AND TRANSPORT, (04.17. 2015),
- ISO 28005-2:2021 (ISO, 2021) EU Port Community System, interface standards for establishing electronic connections. (Security management systems),
- Safe SeaNET 2018 EMSA (European Maritime Safety Association), which must be fulfilled based on AIS-identified ships (SeaNet),
- RIS-2014, AIS has been introduced (CCNR),
- RIS-2018 ECDIS charts have been introduced in cargo shipping (CESNI).

4.1 EU funding for domestic shipping developments

1. Development of the fairway marking system for the entire Hungarian section of the Danube (Fairway project),
2. Construction of a new, modern floating buoy system (including traditional and intelligent buoys) and shore signals, which can be further developed for the following functions:
    - shipping messages,
    - weather forecast,
    - traffic control and statistics,
    - water level map corrections.

4.2 Coexistence of passenger and cargo shipping

The Danube is an international river where free navigation must be ensured based on the Belgrade Convention, the UN AGN regulations and the ICPDR (Zagreb) agreement (ICPDR, 2024). In the field of cargo shipping, as well as in passenger shipping, the following technical parameters are properly regulated:

The vessels' main dimensions coupled units (tugboats and pushers), safety devices and equipment, and night lighting. At the same time, it is important to state that there are very different traffic characteristics in the area of all vehicle groups:

- Tugboats and pushers: Length × Width 320-350 m × 33-35 m, speed: 15-20 km/h,
- Self-propelled vessels: (+1 pusher unit) L × W 180-200 m × 11.40 m, speed 15-20 km/h,
- Cruiser: L × W 110-150 m × 11.40, speed 25-28 km/h,
- Seagull hydrofoil: L × W 27 × 9 m, speed 65 km/h,
- Meteor hydrofoil: L × W 34.6 × 9.5 m, speed 60 km/h,
- Local tourist boats and catamarans: L × W 24-35 m × 6-8.5 m, 20-55 km/h,
- Small boating* (under 12 people/boat): L × W 8-12 m × 4-5.5 m, 12-15 km/h.

All boat groups are equipped with AIS vessel tracking devices except those marked with *.

The current regulations and the ship tracking practice developed for them do not currently apply real-time tracking of object individuals and the method of preventive intervention because the necessary tools have not been used in the field of river navigation so far.

4.3 The issue of navigation discipline and safety

The existing regulations provide a general level of safety for ship navigation, with skippers with clear decision-making ability and professional experience, as well as with transparent weather and flawless technical conditions.

The combined effects of human fatigue, not always ideal technical environment and adverse weather conditions negatively affect human decisions. These factors can also cause mass accidents. Therefore, it is necessary to introduce a permanent dispatch service at specific locations where highly competent specialists control the traffic. This is connected to the HW/SW with an AI technology background, which can intervene online and in real-time.

4.4 Challenges related to waterways and weather

We can encounter several factors that are different from ideal on the Danube route of the Hungarian capital, even during suitable weather conditions.

1. There are 10 road and railway bridges supported by bridge piers on the capital's waterway. The problem is that the shallow water effect that occurs in the case of turbulent flow at particularly low water levels requires a lot of practical navigation experience.
2. The total annual passenger traffic of ships with 30 or more berths reaches 2.5 million.
3. The number of ports reserved for cargo ships and ships designated for technical waiting is 4-6 ports.
4. 9 ports are reserved for hotel shipping, with passenger traffic of 250 000 people/year.
5. 8-10 ports are reserved for program shipping, with passenger traffic of 500 000 people/year.
6. 2-4 ports are reserved for events, with passenger traffic of 1 million people/year.

A significant feature of the ports' location is that they are parallel to the designated international waterway, 4-6 m away. In addition to the current traffic, port navigation poses a great challenge for port operations. Regarding hotel ships, it should be emphasised that double (and triple) parallel moorings are sometimes allowed according to the current regulations. The development of traffic – and the appropriate safety conditions – require the local review of mooring rules. Today, a similarly important task would be introducing central, 24-hour dispatcher supervision of mooring navigation. Furthermore, in connection with this, the introduction of online navigation authorisation operations is necessary to manage FAL documents for departure from the port. In these developments, it is also advisable to apply the navigation characteristics of transit water traffic of cargo ships to port operations, with particular regard to the priority handling of dangerous cargo.

5 5G technology

5.1 5G technology on the Danube section of the capital

The 5G technology, which was installed by VODAFONE on 05.23.2019 at the frequency f = 3.6 GHz, allows the system to be used (Thompson, 2014). Since 03.23.2019, a lifeboat service and AIS automatic unique vessel identification system have been operating on the Budapest Danube.

The EU introduced this in 2015 for all cargo and passenger ships carrying more than 12 passengers. This facilitates developing and applying a pilot control system on the Budapest Danube between 1659.74 river km and 1633 river km.

The pilot plan aims to achieve operational results that make this system suitable for domestic and D-M-R waterway applications.

As seen from international statistics, weather factors and possible technical errors, which can occur unexpectedly on board the most modern ships, play a fundamental role in accident circumstances.

As a result, the above negative effects claim lives, and on the other hand, the built environment is also damaged due to the accident's destructive effects.

To prevent the above, the EU developed the SEVESO-III regulation, which has also been included in the legislation of the Hungarian Disaster Act and supports the determination of the expected safety value and the economic effects of the expected annual number of accidents by calculating probability and applying appropriate mathematical procedures.

The significance of developing the safety system - BIR - is that it contains more detailed regulations regarding hazardous substances and transactions, which also includes considering expected or already occurred accidents when examining the event sequences.

It requires the operator to:

- Pay close attention to the participants in the work processes carried out by contractors/subcontractors of partners contracted in connection with the hazardous activity and display them in the BIR,
- In connection with the activity, the strategy and methodology necessary for monitoring the technological environment "in the spirit of awareness and prevention" must be developed, as a result of which the operators can implement the necessary corrective measures,
- Operators must define the performance indicators used for safety performance evaluation,
- During the revision of the internal protection plan, the operator must present the technologies/techniques and the effective management and control infrastructure used to minimise accident situations related to hazardous materials,
- The operator must prove in the safety documentation the establishment and usability of the operational damage

prevention organisation, together with the related personal, material, technological/technical conditions,

- From the point of view of low molecular weight gases, the following substances appear as wetted substances: e.g., anhydrous ammonia, boron trifluoride, hydrogen sulfide, hydrogen, and methane gases. (These substances mainly belong to renewable and alternative fuels.).

The BIR system, therefore, implements safety conditions that are continuously evaluated during their operation - in response to occurring events - e.g., those that serve the life-cycle safety of the given operated object.

The DunaInfoControl system we propose for implementation aims to ensure the fulfilment of these requirements for all participants in river transport (Péter et al., 2021). The development of the BIR-SIS requires the implementation of the required reports after every incident affecting the safety system and the further development and re-evaluation of the BIR regulation by processing them (The Lawphil Project).

5.2 The possibilities of 5G technology and artificial intelligence

The control system we propose uses a properly adjusted camera system and radar sensors, step by step, with horizontal displacement along the banks, connected into a common network on the defined river section, river banks and bridges. The sampling points are duplicated, with bottom/top visibility at the bridges and tracking by river km section. Using these, data is continuously collected (AIS, speed, heading, hill/valley), with cyclic track-route correction during tracking, which is performed by the AI system with a 0.1 sec update. Continuous high-speed automatic cyclic evaluation of "bubbles" and safety lanes developed for ship and tow/push shapes are applied to interpret the expected situational images. The AI process is used to automatically process signals, combined with the IDM model of water traffic, to predict potential conflict situations and highlight suspected accident situations.

In case of irregularities, the task is to issue warnings and implement diversion. An important task is to provide technical support for an accident or technical failure. For example, a "man in the water" sends a drone life jacket. A circular multipoint info-network connection directly supports boat captains and rescue personnel. An important automatic task is to operate the event evaluation system and process the data, as well as the statistical processing and archiving of the weighted fault tree, irregularity, consequence, FKM position damage and the cause. This also involves the analysis and development of a "self-learning system". All this creates competencies capable of operating the online system and its sustainable development for 24-hour operating conditions.

5.3 DunaInfoControl - The IT background of centralised river traffic control

A fundamental requirement of centralised traffic control is that the operators on duty at the centre have continuous, real-time information about the status of all mobile and static participants in the traffic. In modern traffic control systems, it is increasingly important that AI-supported traffic controllers make the appropriate decisions. The radio frequency bandwidth of the AM/FM communication currently operated by the RSOE does not meet several important requirements. For example, if necessary, there is a requirement to simultaneously conduct direct conversations, video, and other data transmission between ships or between ships and the shore. When determining the maximum channel capacity [bit/s], Shannon's law must be applied, which takes into account the channel bandwidth [Hz], signal power [W] and noise power [W]. The river system needs to be further developed, as the various types of transponders used on individual vessels no longer meet the requirements of a modern centralised control system. The carrier frequencies have GMSK-FM modulation and are used to transmit GPS position data. The signal propagation time of AIS transponders in transmission mode between the vehicle (vessel) and the signal processing location must also be taken into account:

$$\sum TRANS = \sum DATA + TRANStype + SHIFFvel$$

Where:

$\sum TRANS$ is the signal propagation time of the entire data transmission network, from the signal source to the endpoint [s]

$\sum DATA$ is the total data transmission time of the AIS transponder network - in transmission mode [sec]

$$\sum DATA = GPSkonv + SIGNkonv + CPUClk + \\ + INTkonv + 1/f1{,}2 + CPUtime + 1/50 * DISPnew$$

TRANStype is the set sampling cycle time of the AIS type [sec]

$\sum SHIFFvel$ is the instantaneous speed of the ship [m/sec]

Class A and B stations participate in the communication.

Class A stations autonomously report their position every 2-10 seconds, depending on the speed and course change of the ship. When anchored or moored, they report their position at least every 3 minutes.

Class A stations are also capable of sending text messages. This is safety-related information and specific messages regarding the use of AIS.

Class B stations send position reports every 30 seconds if they move faster than 2 knots – otherwise, every 3 minutes.

Key data regarding the RIS AIS system:

- The two AIS frequencies used: 161.976 MHz and 162.025 MHz,
- GMSK-FM modulation.

Due to the listed technical disadvantages, in the DunaInfoControl project, we propose gradually replacing the current RIS AIS system and a step-by-step connection to the already nationally deployed 4G/5G network, initially operating the two systems in parallel.

The operating frequency of 4G / 5G depends on the individual service provider. Usually, it is $f1$ = X * GHz, i.e., $1/f1$ = 10-10 sec.

The data transfer rate is given in Gbit/s and is several orders of magnitude higher than that provided by the AIS system. The carrier frequencies have a so-called QAM quadrature amplitude modulation. Several factors influence the signal's propagation time since the signal transmission is not point-to-point. This information transmission in the cellular network is influenced by the given carrier frequency and the network's traffic load. In this regard, a $T = 0.001$ sec must be considered.

This is much faster than any other widely used communication network. 5G technology has brought significant progress in data transfer speed, capacity and reliable connection. This is very important, for example, in autonomous road and water vehicles. Installing a river IT system along the Danube has now become possible based on the 4G/5G national network. This has several advantages:

1. Ultra-high data transfer speed, which can reach up to 20 Gb/s,
2. Minimal latency at which the response time can be determined in about 10 ms,
3. Huge connectivity, which supports extensive device connections, increasing efficiency.

The DunaInfoControl project is technically open, also in terms of connection to an IT network in which the participants of each type of traffic maintain direct satellite communication links with each other and the control centre. In this regard, a CarpathiaSAT communication satellite project is planned by a Hungarian company and is currently being implemented. This development ensures independence from GPS systems and the transmission of reliable and interference-free broadband information between vehicles participating in traffic and the control centre. The special modems and transverters required for its operation can be solved and manufactured from domestic sources, and there are Hungarian specialist companies and enterprises for this.

The DunaInfoControl project offers a feasible technical solution to avoid mass accidents such as the 2019 Hableány disaster.

In this regard, an important basic requirement is introducing modern, central traffic control supported by artificial intelligence and dynamic vector analysis.

It is also important that the applied IT system - 4G/5G or SAT-based - ensures quick decision-making without delay; otherwise, the system will just run after the events.

6 Proposal for the development of central traffic control

6.1 Development of an online and real-time dispatch centre

It covers the implementation of a two-way flow of all control-related information with high security. This includes checking that all safety-related equipment on the entering vehicle is functioning properly. Intelligent communication monitoring is used. This Centre ensures optimal movements and information storage. It intervenes if the situation does not comply with traffic regulations or a critical situation develops. (After the local commissioning of the Dispatch Centre, it can be developed into a national centre.)

Objectives and requirements: the "intelligent buoy system" currently under installation should be adaptable to HW/SW applications,

- It should be installed on all the Hungarian Danube and Tisza rivers and lakes.
- Its further development should enable the analysis of the causes of accidents by identifying personnel positions and mechanical equipment faults.
- In the event of an accident, it should enable the dispatcher to actively intervene circularly to cooperate with the police, ambulances, disaster management and other bodies (OMSZ).

The development is proposed to be developed in 3 stages:

1. Expansion of the existing HW/SW within a pilot program to set up the dispatch centre in the capital and then to plan it on individual sections of the Danube and Tisza rivers.

2. Establishment of a new IT network with a 5G system, e.g., in the f = 3.6 GHz band.
3. Establishment of a national control centre and several sub-centres.

The result of the development is an integrated online proactive AI-supported system that can be used for safe navigation and thus creates an innovative transport development that complies with EU directives. The following three important quality features should be considered in creating the system:

1. Artificial intelligence and in-vehicle devices.
2. Digitalisation of port entry/exit communication and regulation of traffic priorities.
3. Recurrent training of ship crew with domestically developed simulator navigation, which complies with the requirements of MARITIME TRANSPORT: A SELECTION OF ESSENTIAL EU LEGISLATION DEALING WITH SAFETY AND POLLUTION PREVENTION (2016-EU). Real-time communication and the simultaneous inclusion of multiple stakeholders in the rescue system, with real-time communication, can provide adequate support for resolving the accident situation and increasing rescue efficiency.

The implementation of the pilot project requires the following tasks:

- Surveying the waterways of the capital is an important task. In this regard, studies related to equipment placement must also be carried out. Due to the changing water depths, fluid simulation studies must also be carried out around the bridge piers.
- Determination of high-traffic and high-risk water transport locations - due to the unique requirements of the port environment - to comply with local safety conditions.
- Create the operator control HW/SW system implementation for operational tests.
- Introduction of centralised traffic control with 24-hour supervision and rotating personnel.
- Application of real-time and online IT network (5G) and AI (Artificial Intelligence) technology in decision-making before the emergence of emergencies, technical design and implementation, and commissioning.
- Selection and trial operation of machine-to-machine (M2M) communication devices.
- Installation of modern rescue equipment, drones with central control, and the operational activities of a new organisational unit.
- The dispatch system can also design and implement a training simulator HW / SW and its archived database.
- Application of a training simulator with accident simulations and self-learning SW systems for further training, analysis of accident situations and recurrent training of ship captains.
- Development of an EU-compatible national economic cost/benefit of the system.
- The application of 5G under SIL-3 or SIL-4 conditions, with redundancy and continuous operation, in accordance with 24-hour supervision, ensures accident-free navigation on a given river section and tightens legal consequences.
- Revision of current domestic shipping regulations following EU regulations, organisation of training and competence reviews from the perspective of the qualification of the shipping company and the sailing crew. Development of a modern communication system for establishing ship-port security communication links, with the introduction of EU digitalisation rules (FAL-1-7 data traffic) (Insight EU Monitoring, 2023).

6.2 What can we learn from the operation of the air traffic control system?

First, we can utilise the theoretical foundations that have established the high level of safety and efficiency of the modern control system. Similarly important are the cutting-edge safety-critical techniques that serve control with great efficiency. Artificial intelligence (AI) methods are already being used in more and more transport sectors. HungaroControl signed a contract with an international German-French-English consortium, which began the development of the MATIAS (Hungarian Automated and Integrated Air Traffic System), which is still in use today. The software is based on the French Thales Air Systems EuroCat 2000E program but was adapted to Hungarian needs from the beginning. The system has been operating since December 1999 and is continuously updated and equipped with new capabilities. The software's task is to support air traffic controllers by providing them with all important information.

The renewed software system is served by a modified Red Hat Linux operating system prepared for real-time operation (Red Hat). The FDDI ring has been working flawlessly so far and is being replaced by gigabit Ethernet. In addition to the data (aircraft position, speed, altitude) provided in real-time by seven radars (four Hungarian, two Slovak, and one Romanian), MATIAS also continuously monitors the flight plan data received from the European air traffic control centre. Data on flights affecting Hungarian airspace is stored in Brussels, containing information such as the number of flights, aircraft type, departure and destination stations, and equipment. In addition, MATIAS is connected to similar systems in neighbouring countries and receives the most important information about the aircraft from them minutes before they arrive in the airspace, i.e., where, when, and at what altitude the given aircraft will arrive.

The software also contains data on protected airspaces (e.g., due to military operations) and weather-related information, which is updated every 10 s by the Meteorological Service (OMSZ). MATIAS's most important task is to inform air traffic controllers. A trained controller can handle a maximum of 18-20 aircraft. The Hungarian airspace is always divided into sectors by the controller's supervisor so that no one controller receives more traffic than this. In addition to displaying and recording information, the software can also make forecasts based on the data at its disposal, analyse the position and direction of the aircraft in real-time, predict the development of the airspace situation for 25-30 min and warn the controllers if a conflict situation is expected somewhere. The system can follow the parallel airspace position of 80-100 aircraft and direct 2-300 flights directly to the local airport during peak hours.

7 Development of an optimal water traffic control system

The optimal dynamic vehicle-to-vehicle relationship management also considers the dynamic vehicle-to-infrastructure relationship management. In the future, this will be solved in most cases by an intelligent system installed on board watercraft. At that time, autonomous watercraft management will occur by developing and implementing a robot pilot/robot captain model system. The improved Dispatch Centre will carry this out. It precisely determines the position of every watercraft in its area in its system, calculates in advance and performs optimal concept management.

Our scientific research in Modified Intelligent Driver Model (IDM) models is perfectly applicable and can be further developed in this area (Derbel et al., 2012; Derbel et al., 2013; Péter and Lakatos, 2019). When starting the modelling, it is very important to determine the real traffic conditions and analyse the processes accurately (Derbel et al., 2018; Szauter et al., 2019). The expected vehicle density at the inputs and outputs must be determined (Péter et al., 2020). Finally, validations related to analysing the traffic processes must also be performed. The Intelligent Driver Model (IDM) was developed by (Treiber et al., 2000) for a road traffic simulator. IDM is suitable for simulating and monitoring the longitudinal motion of vehicles (Kesting et al., 2009). Investigate the impact of vehicles equipped with IDM on traffic and travel time evolution.

7.1 Mathematical model of river traffic

The classic IDM is a chain-like microscopic model consisting of n vehicles that describe the longitudinal dynamics of vehicles. The system parameters and coupling functions determine the longitudinal dynamics of the vehicle traffic system, allowing vehicles to adapt their speed to the environment, as seen in the basic Eq. (1), e.g., Treiber et al. (2000):

$$\dot{v}_k = a_k \left[1 - \left(\frac{v_k}{v_k^0} \right)^{\delta} - \left(\frac{s^*(v_k, \Delta v_k)}{s_k} \right)^2 \right] \tag{1}$$

To examine the new equation of motion of watercraft, we consider the actual ship masses m_k (k = 1, 2, ..., n):

$$\dot{v}_k m_k = m_k a_k \left[1 - \left(\frac{v_k}{v_k^0} \right)^{\delta} - \left(\frac{s^*(v_k, \Delta v_k)}{s_k} \right)^2 \right]$$

It is advisable to rearrange the above differential equation for the forward speed into the following form, Eq. (2):

$$\dot{v}_k m_k - m_k a_k \left[1 - \left(\frac{v_k}{v_k^0} \right)^{\delta} - \left(\frac{s^*(v_k, \Delta v_k)}{s_k} \right)^2 \right] = 0 \tag{2}$$

Then, based on the IDM model, the k-th equation of the differential equation system for the motion of ships can be written in the following form:

$$\ddot{x}_k m_k - m_k a_k \left[1 - \left(\frac{\dot{x}_k}{v_k^0} \right)^{\delta} - \left(\frac{s_0 + \dot{x}_k T + \frac{\dot{x}_k \left(\dot{x}_{k-1} - \dot{x}_k \right)}{2\sqrt{ab}}}{\left(x_{k-1} - x_k \right) - l_k} \right)^2 \right] = 0$$

$$\left(k = 1,\ 2,\ \ldots,\ n \right)$$

Where the meaning of each parameter is as follows:

- a_k is the maximum acceleration of the k-th vehicle,
- x_k is the position of the k-th vehicle,
- $\dot{x}_k = v_k$ is the speed of the k-th vehicle,
- $\ddot{x}_k$ is the acceleration of the k-th vehicle,
- v_0 is the desired speed of the k-th vehicle,

- $x_{k-1} - x_k$ is the distance between the centre of gravity of the (k–1)-th and k-th vehicles,
- s_k is the distance between the (k–1)-th and k-th vehicles (the vehicle length, in the case of our article, varies by vehicle; Fig. 1) (Péter et al., 2023),
- $\Delta v_k = v_{k-1} - v_k$ is the difference between the speed of the (k–1)-th and the k-th vessel,
- T Safe time headway,
- a, the Maximum acceleration,
- b, Comfortable deceleration,
- δ, Acceleration exponent,
- s_0 Minimum distance.

We then consider the resistances acting on the ship, for each k-th ship:

$$\ddot{x}_k m_k - m_k a_k \left[1 - \left(\frac{\dot{x}_k}{v_k^0} \right)^{\delta} - \left(\frac{s_0 + \dot{x}_k T + \dfrac{\dot{x}_k \left(\dot{x}_{k-1} - \dot{x}_k \right)}{2\sqrt{ab}}}{\left(x_{k-1} - x_k \right) - l_k} \right)^2 \right]$$
$$+ E_{k,1} + E_{k,2} + E_{k,3} = 0$$

Where:

- $E_{k,1} = E_{k,1}(\dot{x}_k \pm v, A, C, \rho)$ is the wave resistance force for the k-th ship,
- $E_{k,2} = E_{k,2}(\dot{x}_k \pm v, A, C, \rho)$ is the force against the progress for the k-th ship,
- $E_{k,3} = E_{k,3}(\dot{x}_k \pm v, \pm v, A, C, \rho)$ is the shape resistance force for the k-th ship.

In the above cases, the independent variables are the following:

- $v = v(t)$ - water velocity in the direction of travel,
- A - surface perpendicular to the direction of travel,
- C - shape resistance factor,
- ρ - density of water.

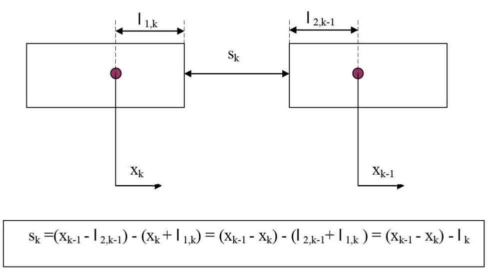

Fig. 1 The distance s_k between successive vehicles (Péter et al., 2023)

The above empirical functions can be practically well determined by small-sample modelling or by using the finite element method. Based on the above, the dynamic model of the consecutive n-element ship chain – which can already be the basis of a model predictive control procedure – is described using the following nonlinear differential equation system:

$$\ddot{x}_1 m_1 - m_1 a_1 \left[1 - \left(\frac{\dot{x}_1}{v_1^0} \right)^{\delta} - \left(\frac{s_0 + \dot{x}_1 T + \dfrac{\dot{x}_n \left(\dot{x}_0 - \dot{x}_1 \right)}{2\sqrt{ab}}}{\left(x_0 - x_1 \right) - l_1} \right)^2 \right]$$
$$+ E_{1,1} + E_{1,2} + E_{1,3} = 0$$

$$\ddot{x}_2 m_2 - m_2 a_2 \left[1 - \left(\frac{\dot{x}_2}{v_2^0} \right)^{\delta} - \left(\frac{s_0 + \dot{x}_2 T + \dfrac{\dot{x}_2 \left(\dot{x}_1 - \dot{x}_2 \right)}{2\sqrt{ab}}}{\left(x_1 - x_2 \right) - l_2} \right)^2 \right]$$
$$+ E_{2,1} + E_{2,2} + E_{2,3} = 0$$

$$\ddot{x}_k m_k - m_k a_k \left[1 - \left(\frac{\dot{x}_k}{v_k^0} \right)^{\delta} - \left(\frac{s_0 + \dot{x}_k T + \dfrac{\dot{x}_k \left(\dot{x}_{k-1} - \dot{x}_k \right)}{2\sqrt{ab}}}{\left(x_{k-1} - x_k \right) - l_k} \right)^2 \right]$$
$$+ E_{k,1} + E_{k,2} + E_{k,3} = 0$$

$$\ddot{x}_n m_n - m_n a_n \left[1 - \left(\frac{\dot{x}_n}{v_n^0} \right)^{\delta} - \left(\frac{s_0 + \dot{x}_n T + \dfrac{\dot{x}_n \left(\dot{x}_{n-1} - \dot{x}_n \right)}{2\sqrt{ab}}}{\left(x_{n-1} - x_n \right) - l_n} \right)^2 \right]$$
$$+ E_{n,1} + E_{n,2} + E_{n,3} = 0$$

We then briefly discuss the role of the three resistors under consideration in the above differential equation system.

8 The role of wave resistance, force against and shape resistance in the model

In our case, we are examining surface ships for which the buoyancy force is equal to the mass of the displaced water. These are called displacement ships. As ships advance, they must overcome three types of resistance: wave resistance, force against progress and form resistance.

8.1 Wave resistance

Water flowing and passing by the ship's side exerts frictional resistance to its motion, called wave resistance.

8.2 The Force Against Progress

This is caused by the ship's parts below the waterline (e.g., the rudder and its support structure, the propeller shaft, bearings and, on large ships, the shock absorber plates at the junction of the ship's bottom and sidewall). Furthermore, at high speeds or in stormy winds, surface waves and the air resistance of the hull and superstructure above the water surface can also be significant in this case. A particularly important area in the case of watercraft is the application of modern vehicle diagnostics,

8.3 Form resistance

Some water flowing along the hull at the ship's speed forms a thin boundary layer near the ship's wall. In the thin layer, water particles rub against each other, creating resistance to the ship's motion. The particles moving at a higher relative speed on the outside force the flow to rotate. A swirling motion is formed. The vortices break away from the hull, which results in greater friction, and therefore greater resistance, between the water particles. This is a turbulent flow. (Kármán vortices are formed.) In the case of watercraft, it is also important to take into account the weather conditions based on the aerodynamic parameters of the given vehicles (Brúnó and Lakatos, 2024a). In addition to the above, related model tests are also important in the investigations (Brúnó and Lakatos, 2024b). It is noteworthy that turbulence studies play a special role in modelling (Brúnó and Lakatos, 2024c). As the ship moves forward, it creates a pressure wave in front of it, and the flow is deflected to the side and accelerated due to the hull widening after the bow. It decreases as we examine the static pressure along the ship's length. Towards the rear, the hull's shape narrows again, resulting in a decrease in water speed. This, in turn, increases the static pressure around the wall. However, the pressure at the ship's bow is greater than at the stern. However, the difference between the two hinders the ship's progress. Essentially, this formation can be called form resistance. Considering the energy demand, the frictional resistance accounts for the largest energy demand if the ship's speed is low. However, if the speed increases, the resistance from wave formation increases, increasing the energy demand (Solymos, 2023).

9 The role of the Saint-Venant equation in modelling

One form of the shallow water model is the Saint-Venant equation (SVE). An important feature of this model is that the density of the fluid is considered constant. The SVE determines the surface area of the fluid at cross-sectional points x and at different times t. The equation considers the fluid pressure and flow velocity at points (x, t). The SVE is a hyperbolic partial differential equation system, the solution of which is, in practice, achieved by applying numerical integration. E.g., (Sukron et al., 2021) apply a semi-discrete method to integrate the system of differential equations in a finite space. In doing so, the SVE is transformed into ordinary differential equations (ODEs). The authors used a fourth-order Runge-Kutta method for numerical integration. Compared to other ODE-solving methods, it has been found that this method has a lower error and higher accuracy. SVE is widely used in modelling open channel flows and ocean simulations, such as tsunamis and tidal waves. The Saint-Venant equation can account for changes in wave resistance during modelling.

The Saint-Venant equation (SVE) is suitable for calculating the magnitude of vertical waves generated during the change in time t along an arbitrary x_i-axis perpendicular to the flow direction. Based on this, a continuous wave surface forecast can be given for initial values measured in discrete time ranges along the designated x_i (i = 1, 2, …, n) axes on the critical section of the Danube River in Budapest.

10 Development of the IDM model

When developing the IDM model, we consider the real capabilities of the vehicles. Based on the modification, the driver or autonomous robot pilot now has to consider the behaviour of the watercraft moving in front of them and following them, - therefore, we developed and tested a new modified IDM model. This considers the complex, real-world traffic environment and the joint dynamics of the vehicles (Péter and Lakatos, 2019). It can be stated that autonomous vehicle industry research can be extended and generalised to autonomous watercraft and their control. Of course, two important properties must be carefully considered:

1. The characteristics and properties of water traffic,
2. The characteristics and properties of water as a track.

Measurements can analyse these but can also be modelled, for example, with the Saint-Venant differential equations, advanced partial differential equation systems and methods, and software suitable for finite element flow modelling.

11 Concept of a port and combined traffic system adapted to the shipping system

On the one hand, due to long-term development goals, on the other hand, for managing the structure of transit and local traffic and validating the reception of international shipping data, we consider it appropriate to establish two independent tracking systems in the AIS system. In this way, these two groups can be handled separately in the future.

- Ships heading abroad from the departure station (which only operates on the domestic river section – (category A), and,
- Ships entering the shipping route from a domestic port or a border station for domestic docking (category B).

12 Conclusions

The control centre must be designed for the Danube traffic in 2030, considering that by then the current ship traffic in freight and passenger transport will be at least 4 times higher. This traffic demand cannot be regulated in any other way, with adequate safety on an international inland waterway of paramount importance. In addition to automated functions, introducing human action that checks compliance with the rules following international practice provides additional opportunities to limit the expected chance of emergencies. It should be emphasised here that the Danube also causes difficult navigation conditions in many places outside the capital, which are currently being improved with physical interventions due to the limited water depth and low/high water compensating for fluctuations. Therefore, channel narrowing is also carried out in some places, which may require a change in traffic direction and special management regulations in a given place. An increase in inland navigation on the Danube and other domestic waters can be forecast in advance, which will also force a transformation of traffic management.

We also consider the significant role and practical training of integrated domestic and international transport modes – the so-called containerisation – related to the topic. The following areas are also important:

1. Overview of the spread of 5G IT systems and the expected social consequences of AI applications, presenting the centralised water traffic management system as an example.
2. Consideration and application of the ES-TRIN/2017 standards and recommendations for inland and coastal shipping and ports (CESNI, 2017).
3. National defence applications of modern redundant IT systems.

As with any widely applicable IT system used in civil life, e.g., this installed microwave transceiver and the 5G-based reliable communication network, there are also national defence and military applications. Therefore, it is also advisable to comply with the so-called MIL requirements (standards) in this area (Simpson, 2025).

- Implementation of IT connection with the already established and interference-protected high-speed optical fibre communication networks,
- Expansion of SAT connections between control points,
- Continuously ensuring the operability of the established wired and wireless cellular IT network with alternative detours in the event of classified events (ABV disaster or armed conflict). In addition to the above, it is important that both the interactive control centre and the autonomous control system, which will be developed later, comply with the MIL-STD 461 standard (Department of Defense Interface Standards, 2017). It must resist external ECM and have effective cyber protection since malicious external interventions into the control and communication system cannot be ignored.

4. Teaching a modern approach to the human-machine relationship in secondary and higher education institutions, disseminating an innovative technical-scientific approach.
5. The environmental impact study may include - in connection with our current proposal - the widespread use of alternative fuels (LNG or H2) in river navigation instead of the currently widespread diesel.
6. Coordination of domestic transport systems (ship/rail/road) in freight traffic and increased use of container transshipment stations - this also serves to protect the real environment,
7. Cost analyses and expected business benefits, including HW and SW license sales.

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References

Brúnó, P., Lakatos, I. (2024a) "Analysis of the aerodynamic parameters of road vehicles affected by weather conditions", Chemical Engineering Transactions, 114, pp. 1033–1038. https://doi.org/10.3303/CET24114173

Brúnó, P., Lakatos, I. (2024b) "Theoretical study of the effect of weather conditions on vehicle aerodynamic properties", Engineering Proceedings, 79(1), 83. https://doi.org/10.3390/engproc2024079083

Brúnó, P., Lakatos, I. (2024c) "Comparison of different turbulence models and wall treatment methods for vehicle aerodynamics investigations", Periodica Polytechnica Transportation Engineering, 52(1), pp. 67–74. https://doi.org/10.3311/PPtr.22671

CCNR "Key RIS technologies", [online] Available at: https://www.ccr-zkr.org/12040600-en.html [Accessed: 05 June 2025]

CESNI "River Information Service", [online] Available at: https://ris.cesni.eu/30-en.html [Accessed: 05 June 2025]

CESNI (2017) "European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN)", [pdf] European Committee for drawing up Standards in the field of Inland Navigation, Strasbourg. Available at: https://www.cesni.eu/wp-content/uploads/2017/07/ES_TRIN_2017_en.pdf [Accessed: 05 June 2025]

Department of Defense Interface Standards (2017) "MIL-STD-461F Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment", Department of Defense Interface Standards, Arlington, VA, USA. Available at: https://s3vi.ndc.nasa.gov/ssri-kb/static/resources/MIL-STD-461G.pdf [Accessed: 05 June 2025]

Derbel, O., Péter, T., Mourllion, B., Basset, M. (2018) "Generalized velocity–density model based on microscopic traffic simulation", Transport, 33(2), pp. 489-501. https://doi.org/10.3846/16484142.2017.1292950

Derbel, O., Péter, T., Zebiri, H., Mourllion, B., Basset, M. (2012) "Modified intelligent driver model", Periodica Polytechnica Transportation Engineering, 40(2), pp. 53–60. https://doi.org/10.3311/pp.tr.2012-2.02

Derbel, O., Peter, T., Zebiri, H., Mourllion, B., Basset, M. (2013) "Modified intelligent driver model for driver safety and traffic stability improvement", IFAC Proceedings Volumes, 46(21), pp. 744–749. https://doi.org/10.3182/20130904-4-JP-2042.00132

Dick, P. (2015) "DPC Advance Preview of the 2015 EC. Progress Report for Bosnia and Herzegovina", DPC Democratization Policy Council, Berlin, Germany.

Directive, E. P. (2004) "On harmonised standards for inland waterway transport in the Community on river transport information services" Directive of the European Parliament and of the Council, Brussels, Belgium. [online] Available at: https://eur-lex.europa.eu/procedure/EN/2004_123 [Accessed: 05 June 2025]

van Essen, H., van Wijngaarden, L., Schroten, A., Sutter, D., Schmidt, M., Brambilla, M., Maffii, S., El Beyrouty, K., Morgan-Price, S., Andrew, E. (2019) "State of play of Internalisation in the European Transport Sector", European Commission. ISBN: 978-92-76-01413-3 https://doi.org/10.2832/537526

European Parliament and the Council of the European Union Directive, 2005/44/EC of the European Parliament and of the Council of 7 September 2005 on harmonised river information services (RIS) on inland waterways in the Community. Available at: https://www.fao.org/faolex/results/details/en/c/LEX-FAOC054037/ [Accessed: 05 June 2025]

European Parliament and the Council of the European Union Directive, 2010/65/EU of the European Parliament and of the Council of 20 October 2010 on reporting formalities for ships arriving in and/or departing from ports of the Member States and repealing Directive 2002/6/EC. Available at: https://www.fao.org/faolex/results/details/fr/c/LEX-FAOC098591/ [Accessed: 05 June 2025]

ICPDR (2024) "Shared waters – joint responsibilities: ICPDR Annual Report 2023", International Commission for the Protection of the Danube River, Vienna, Austria.

Insight EU Monitoring (2023) " EU Parliament puts more traffic data in digital format", [online] Available at: https://ieu-monitoring.com/editorial/eu-parliament-puts-more-traffic-data-in-digital-format/417338 [Accessed: 05 June 2025]

ISO (2021) "ISO 28005-2:2021 Ships and marine technology – Electronic port clearance (EPC) Part 2: Core data elements", International Organization for Standardization, Geneva, Switzerland.

Kesting, A., Treiber, M., Helbing, D. (2009) "Agents for traffic simulation", Physics and Society. ISBN 978-1-4200-7023-1 https://doi.org/10.1201/9781420070248.ch11

Mező, G. (2019) "PannonRIS és Dunai FIS Portál" (River Information System Telecommunications and System Engineering Solutions), [pdf] Rádiós Segélyhívó és Infokommunikációs Országos Egyesület. Available at: https://www.huport.eu/wp-content/uploads/2019/11/Mez%C5%91_Gergely-FAIRWAY-PannonRIS-FIS-Portal.pdf [Accessed: 05 June 2025]

Ministry of National Development (NFM) (2011) "57/2011. (XI. 22.) NFM rendelet a víziközlekedés rendjéről" (57/2011 (XI. 22.) NFM Decree on the regulation of water transport), Budapest, Hungary. [online] Available at: https://net.jogtar.hu/jogszabaly?docid=a1100057.nfm [Accessed: 05 June 2025] (in Hungarian)

Red Hat "Red Hat Enterprise Linux, (10)", [computer program] Available at: https://www.redhat.com/en/technologies/linux-platforms/enterprise-linux [Accessed: 05 June 2025]

Péter, T., Lakatos, I. (2019) "Vehicle dynamic-based approach for the optimisation of traffic parameters of the intelligent driver model (IDM) and for the support of autonomous vehicles driving' ability", Acta Polytechnica Hungarica, 16(3), pp. 121–142. https://doi.org/10.12700/APH.16.3.2019.3.7

Péter, T., Götz, S., Bóta, J. (2021) "A hajózás biztonságának növelése a DunaInfoControl® - modern irányítás bevezetésével" (Increasing Safety in Shipping with the Introduction of the DunaInfoControl® Modern Control System), Közlekedéstudományi Szemle, 71(5), pp. 45–62. (in Hungarian) https://doi.org/10.24228/KTSZ.2021.5.4

Péter, T., Háry, A., Szauter, F., Szabó, K., Vadvári, T., Lakatos, I. (2023) "Mathematical Description of the Universal IDM - some Comments and Application", Acta Polytechnica Hungarica, 20(7), pp. 99–115. [online] Available at: https://acta.uni-obuda.hu/Peter_Hary_Szauter_Szabo_Vadvari_Lakatos_136.pdf [Accessed: 05 June 2025]

SeaNET "SeaNet Yachts", [online] Available at: https://www.yachtworld.com/boats-for-sale/broker-seanet-yachts-33396/ [Accessed: 05 June 2025]

Simpson, S. (2025) "MIL-STD Standards – Guide to Military Specifications and Compliance", [online] Available at: https://www.defenseadvancement.com/resources/mil-std-specifications-guide/ [Accessed: 05 June 2025]

Solymos, A. (2023) "Minden, amit tudni kell a hajóellenállásról - első rész" (Everything you need to know about ship resistance - Part one), Aqua Magazine, 160, pp. 1–3. [online] Available at: https://aquamagazin.hu/minden-amit-a-tudni-kell-a-hajoellenallasrol-elso-resz/?p=49974 [Accessed: 05 June 2025] (in Hungarian)

Sukron, M., Habibah, U., Hidayat, N. (2021) „Numerical solution of Saint-Venant equation using Runge-Kutta fourth-order method", IOP Publishing, 1872(1), 012036. https://doi.org/10.1088/1742-6596/1872/1/012036

Szauter, F., Rózsás, Z., Péter, T., Lakatos, I. (2019) "Integrated application of network traffic and IDM models in the test laboratory analysis of autonomous vehicles and electric vehicles", International Journal of Heavy Vehicle Systems, 1, pp. 1-18. https://doi.org/10.1504/IJHVS.2019.10024659

The Lawphil Project "BIR Rules and Regulations", [online] Available at: https://lawphil.net/administ/bir/rr/rr.html [Accessed: 05 June 2025]

Thompson, J., Ge, X., Wu, H.-C., Irmer, R., Jiang, H., Fettweis, G. (2014) "5G wireless communication systems: prospects and challenges part 2 [Guest Editorial]", IEEE Communications Magazine, 52(5), pp. 24–26. https://doi.org/10.1109/MCOM.2014.6815889

Treiber, M., Hennecke, A., Helbing, D. (2000) "Congested traffic states in empirical observations and microscopic simulations", Physical Review E, 62(2), pp. 1805–1824. https://doi.org/10.1103/PhysRevE.62.1805