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Possibilities of Implementation of the System of Automatic Indication of Safe Clearance under the Bridge in Poland

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Piotr Durajczyk[1], Natalia Drop[2], Marianna Maruszczak[3]

Abstract:

Purpose: *In relation to the observed climate changes, the governments of countries- especially those of the European Union- pay more and more attention to the influence of the transport system on the natural environment when creating transport policy. Priority is given to the development of the branches of transport which are least harmful to the environment - rail transport and inland waterways. Due to difficult navigation conditions and poor condition of waterways in Poland, solutions are being implemented to improve the efficiency of inland navigation. One of such solutions is.*
Approach/Methodology/Design: *The first part of the article describes the issues related to inland navigation in Poland, the River Information Services (RIS) system and describes the principles of operation of the system of automatic indication of safe clearance under the bridge. A cost analysis was then made to implement such a system on all bridges with a clearance of less than 5.25 meters on the Oder Waterway.*
Findings: *The system of automatic indication of clearance under the bridge can significantly contribute to safer navigation, more efficient fleet utilization and reduced fuel consumption.*
Practical Implications: *The analysis presented in the paper can serve as a guideline for state authorities and waterway managers regarding the rationale for implementing the system of automatic indication of safe clearance under the bridge and the financial outlays that should be incurred for implementing such a solution.*
Originality/Value: *Inland navigation in Poland is very poorly developed, therefore it is necessary to analyze the possibility of implementing solutions aimed at improving its operation. The system for measuring clearance under bridges is a new solution on a national scale, but one that has a significant impact on the safety and optimization of navigation.*

Keywords: *Inland navigation, RIS system, management.*

JEL classification: *Q00, Q01.*

Paper Type: *Case study.*

[1]*Maritime University of Szczecin, Faculty of Economics and Transport Engineering, ORCID ID: 0000-0003-1447-973X, p.durajczyk@am.szczecin.pl*
[2]*Maritime University of Szczecin, Faculty of Economics and Transport Engineering, ORCID ID: 0000-0002-6148-7815, n.drop@am.szczecin.pl*
[3]*Maritime University of Szczecin, Faculty of Economics and Transport Engineering, ORCID ID: 0000-0001-8089-2042, m.maruszczak@am.szczecin.pl*

1. Introduction

In relation to the observed climate changes, the governments of countries- especially those of the European Union- pay more and more attention to the influence of the transport system on the natural environment when creating transport policy. Priority is given to the development of the branches of transport which are least harmful to the environment - rail transport and inland waterways. The latter is explicitly mentioned in EU strategic documentation, including the White Paper - Roadmap to a Single European Transport Area - Towards a competitive and resource-efficient transport system. The possibility of IWT, however, depends largely on the natural conditions of individual countries, e.g. the density of the waterway network or climatic conditions.

Therefore, IWT plays a significant role only in countries with an internationally important waterway network (class IV and above). The highest shares of inland waterway transport in terms of tonne-kilometres were recorded in Germany (over 36.4%), the Netherlands (34%) and Romania (10%). For comparison, the share of Poland in tonne-kilometres transported by inland waterways was 0.6% (Eurostat, 2020a). The Netherlands, Belgium and Germany had the largest share in container transport, together representing more than 94% of all container transport in the EU (Eurostat, 2020b).

The fulfilment of the boundary condition, i.e., the existence of waterways with sufficient parameters for inland navigation, is not sufficient for inland navigation to be an alternative to other transport branches. Creating favourable conditions for shipping requires the simultaneous existence of three basic elements (Jerzyło and Ślączka, 2016):

- waterway of the appropriate class,
- ports with the necessary capacity,
- a fleet compatible in size and shape with navigational conditions of the waterway, technical conditions in the ports and requirements imposed by the cargo.

Traditionally, inland navigation has carried mainly bulk cargo such as coal, mineral oil products, ores, building materials, chemicals, containers, agricultural products and metals (CCNR, 2017; Statistics Poland, 2019). This has a historical basis, as for centuries river transport was the main means of transporting agricultural and mining cargo from industrial basins to, for example, coastal ports or other large urban centres, which were precisely concentrated in the basins of the main waterways. Half of Europe's population lives close to the coast or inland waterways, and most of Europe's industrial centres can be reached by inland waterway (European Court of Auditors, 2015). However, due to the development of transport technologies, containerised cargo transport is currently dominating and increasingly replacing bulk transport.

According to statistical data, container transport accounts for 18% of the total transport work in the EU. The structure of container transport differs between transport modes. Rail and sea transport, in particular deep sea shipping and short sea shipping, account for the largest share (Eurostat, 2019). For inland waterway transport, container transport accounted for 10% of total inland waterway transport in the EU (Eurostat, 2020b).

Numerous scientific works analyse the potential of inland shipping in relation to handling containerised cargo in the so-called deep hinterland. These analyses concern among others:

- optimal business model for operating this type of shipping (Williamsson *et al.*, 2020),
- efficiency of container terminals in inland shipping (Wiegmans and Witte, 2017),
- competitiveness of intermodal river transport (Wiegmans and Konings, 2015),
- selection of even more environmentally friendly river vessels (Tan *et al.,* 2021),
- characteristics of the inbound and outbound container relations from the seaport inland (Fazi *et al.,* 2020).

Research also highlights the fact that IWT is one of the most environmentally friendly modes of transport (Bonk and Kowalska, 2020). An additional advantage highlighted by studies is the lower operating costs compared to other transport modes. This is due to the higher capacity of a single mode of transport. In the case of containerised cargo, river transport can carry 470 TEU at a time. Assuming that two 20' containers can fit on a large truck, 235 trucks are needed to transport this amount of containers. This results in a smaller carbon footprint for cargo transported by inland waterway. One river ship emits 33.4 gr Co2 to the atmosphere per 1 tkm. In comparison, a lorry emits 164 gr/tkm (European Commission, 2011).

In literature we can also find a lot of information pointing to the development and improvement of information technology. It is indicated, among others, on:

- improving the RISS-GPS navigation system, through azimuth updates and magnetometer calibration technology, resulting in improved precision of the overall navigation system (Zhang *et al.*, 2021),
- enhance safety by repairing ship trajectory, modeling engine speed and predicting fuel consumption by using an advanced neural network, Long Short-Term Memory (LSTM) (Yuan *et al.*, 2020),
- innovative decision support model based on the concept of Automatic Hazard Identification System (AHIIS) in inland navigation, which is part of RIS (Miciuła and Wojtaszek, 2019).

2. Waterways in Poland, with Special Emphasis on the Odra Waterway

The specificity of inland waterways in Poland - in terms of their length and spatial layout - has not changed significantly for many years, which in turn affects the demand for freight transport by inland navigation and the technical parameters of the rolling stock used in this branch. The low level of development of inland waterways in Poland in many cases makes it impossible to keep up with the growing transport needs (Deja *et al.,* 2018). The main obstacles for inland navigation in Poland include (Jerzyło and Ślączka, 2016):

- low and varied technical performance on waterways,
- lack of adequate navigational markings and lighting,
- the variation of the minimum depths and their too low level,
- non-uniform parameters concerning the width of navigable waterways, curve radii, bridge clearance heights, lock parameters.

The Regulation of the Council of Ministers of 7 May 2002 divides, classifies and defines the minimum parameters of Polish inland waterways. The main criterion for the division is the size of vessels or convoys allowed to navigate on a given section in terms of dimensions, i.e. length and width and minimum height under the devices crossing the waterway (Woś, 2016). In this way, 7 classes of waterways were distinguished, and the rank of a waterway increases with its class: class Ia to III roads are roads of regional importance, and classes IV to Vb are roads of international importance. Division and minimum requirements for particular classes of waterways are presented in Figure 1.

***Figure 1**. Classification of inland waterways*

Waterway	Waterway class	Motor vessels and barges				Push kits				Minimum clearance under bridges over the WWZ
		general characteristics				general characteristics				
		Max length	Max width	Max draught	load capacity	length	width	draught	load capacity	
		L(m)	B(m)	d(m)	T(t)	L(m)	B(m)	D(m)	T(t)	H(m)
of regional importance	Ia	24	3,5	1,0						3,0
	Ib	41	4,7	1,4	180					3,0
	II	57	7,5-9,0	1,6	500					3,0
	III	67-70	8.2-9,0	1,6-2,0	700	118-132	8,2-9,0	1,6-2,0	1000-1200	4,0
of international importance	IV	80-85	9,5	2,5	1000-1500	85	9,5	2,5-2,8	1250-1450	5,25 lub 7,0
	Va	95-110	11,4	2,5-2,8	1500-3000	95-110	11,4	2,5-3,0	1600-3000	5,25 lub 7,0
	VB					172-185	11,4	2,5-3,0	3200-4000	

***Notes:** 1) The draught value is determined for a particular waterway, taking into account the local conditions; 2) Taking into account the safe distance of not less than 30 cm between the highest point of the ship's structure or cargo and the lower edge of the structure of a bridge, pipeline or other device crossing the waterway; 3) The following values are determined for the carriage of containers: 5.25 m for vessels carrying containers in two layers, 7.00 m for*

vessels carrying containers in three layers, where 50% of containers may be empty, otherwise ballasting is to be provided; 4) Some existing waterways may be considered as Class IV due to the maximum length of vessels and pushed convoys, although their maximum width is 11.4 m and maximum draught is 3.0 m; 5) The first value refers to the present state and the second to the prospective state and in some cases takes into account the present state; 6) WWŻ - the highest navigable water, an established water level beyond which navigation is prohibited.
***Source:** Regulation of the Council of Ministers of 7 May 2002 on the classification of inland waterways*

Most of the Polish inland waterways are class I - III, i.e., roads of regional importance on which only small vessels can move. There are few roads meeting the requirements of classes IV and V, which means that the transport capacity of the Polish inland waterway network is also low. The best developed Polish waterway is the Oder Waterway. Although it does not meet current transport needs, it handles 70% of the total Polish inland freight volume in domestic and international relations (Woś, 2016). The Oder Waterway, due to the existing diversity of its structures and operational parameters, can be divided into the following shipping sections:

- The upper channelised Oder (from Kędzierzyn-Koźle [km 95.6] to Brzeg Dolny [km 282.6]), where the Oder River overcomes a gradient of 62.5 m through 23 water stages located on the main navigation route. A transit depth of 1.8 m is ensured throughout the entire navigation season.
- The free-flowing Middle Oder River (from Brzeg Dolny [km 281.6] to the mouth of the Nysa Łużycka River [km 542.4]), which has the smallest transit depths (directly below the barrage in Brzeg Dolny, for a considerable part of the navigation season, the depths drop below 1.0 m).
- The free-flowing Middle Oder (from the mouth of the Nysa Łużycka [km 542.4] to the mouth of the Warta River [km 617.6]), in which the Oder is a border river and due to the poor condition of the regulating structures there are numerous millings lowering the transit depth. In addition, navigation is impeded by four bends with a radius of 600.0 m.
- The free-flowing Lower Oder River (from the mouth of the Warta River [km 617.6] to Szczecin [km 739.9]), whose extension is the estuary section known as the "Maritime Oder". This section of the waterway has variable parameters:
  - From Kostrzyn to Piasek [km 683], where the Oder River is characterised by a changeable current course and numerous washings,
  - Below km 683.0 where the spurs end and the flow conditions are defined by a steep drop in longitudinal gradient,
  - Szczeciński Węzeł Wodny (Western Odra, Eastern Odra, Regalica, the Klucz - Ustowo Trench), where the waterway has the parameters of a waterway of international importance with some deviations.

2.1 Ratification of the AGN Agreement

The development of inland waterway transport in Poland became one of the priorities after the change of government in 2015. In the first stage of the work on the revitalisation of inland waterway transport, the government commissioned a study entitled Assumptions to the plans for the development of inland waterways in Poland for 2016-2020 with an outlook until 2030, which identified investment priorities for the restoration of the transport function of the Odra Waterway. This document, adopted by Resolution No. 79 of the Council of Ministers of 14 June 2016, was the basis for the Republic of Poland to sign the European Agreement on Main Inland Waterways of International Importance (the so-called AGN Agreement). The AGN Agreement is a basic document drawn up by the United Nations Economic Commission for Europe (UNECE), indicating the directions of development for the inland waterway network in Europe, which aims to: introduce a legal framework that will establish a coordinated plan for the development and construction of an inland waterway network of international importance, based on agreed infrastructure and operational parameters.

- The AGN Convention assumes that three of the created inland navigation routes will run through the territory of Poland (AGN Convention),
- The E-30 waterway connects the Baltic Sea with the Danube River in Bratislava, and its course in Poland covers the Oder River from Świnoujście to the Czech border,
- Waterway E-40 connects the Baltic Sea with the Black Sea and its course in Poland includes the Vistula River to Gdansk to Warsaw, the Narew River and the Bug River to Brest,
- The E-70 waterway links the Netherlands with Russia and Lithuania, and in Poland it covers the Oder River from the mouth of the Oder-Havel canal to the mouth of the Warta River at Kostrzyn, the Vistula-Odra waterway and, from Bydgoszcz, the Lower Vistula and Szkarpawa or Vistula-Gdańsk.

The course of these waterways is shown in Figure 2.

Figure 2. *International waterways in Poland*

Source: *http://actaenergetica.org/article/en/the-lower-vistula-in-the-aspect-of-the-e40-and-e70-international-shipping-routes.html?tab=article.*

The premises of the future policy of the European Union create serious challenges facing both Poland, and individual regions. It should nonetheless be noted that in order to receive the E designation, a waterway must meet the navigability requirements for Class IV and higher. Moreover, the AGN Convention imposes a number of requirements on the construction, modernisation and operating conditions of waterways of international importance. The most important ones from the point of view of this article are:

- While upgrading Class IV waterways (as well as smaller regional waterways) it is recommended that at least Class Va parameters are maintained;
- new waterways designated E should meet at least the requirements of class Vb (a minimum draught of 2,80 m must be ensured);
- While upgrading existing waterways and/or building new ones, the navigability of larger vessels and convoys should always be taken into account;
- on waterways with variable draught levels, the draught recommendation should correspond to the average draught reached or exceeded for 240 days a year (or 60% of the operating period). If possible and economically justifiable, the value of the recommended height under bridges (5.25, 7.00 or 9.10 m) should be guaranteed during the period of the highest inland water level;
- uniform class, draught and height under bridges should be ensured for the whole waterway or at least significant sections thereof.

Three separate groups of obstacles preventing Polish waterways from obtaining the status of international roads can be identified on this basis:

1. Strategic bottleneck - the Oder River from Widuchowa to Szczecin;
2. Basic bottlenecks:
   2.1. River Odra from Kędzierzyn-Koźle to Widuchowa and the Gliwice Canal,
   2.2. the Vistula River from Warsaw to Płock and from Włocławek to Gdańsk,
   2.3. the Bug River from Brześć to Zegrzynski Lake,
   2.4. Żerań Canal from Zegrzyński Lake to the Vistula River,
   2.5. the Vistula-Odra waterway;
3. the missing link - the Oder-Danube-Elbe Canal.

In order to integrate IWT into the intermodal transport chain it is necessary (once the prerequisite of good waterway characteristics is fulfilled) to implement ICT systems for efficient data/information transfer between the IWT stakeholders (waterway and shipping administrations, port and terminal managers, ship operators and ship crews). The digitalisation of information exchange in IWT should be based on the River Information System RIS.

3. River Information Systems RIS

RIS is a tool for organising and managing transport on inland waterways. It is a broadly defined service package, with different services aimed at optimising traffic and transport flows (Durajczyk, 2011). There is no single accepted definition of RIS in Europe. Each country decides to which extent it will implement RIS. In Germany, for example, RIS is defined in very general terms as a broad service package with different services to optimise traffic flows and transport in order to make shipping safer and more efficient. Whereas according to Directive 2005/44/EC of the European Parliament and of the Council of 7 September 2005 RIS can be defined as harmonised information services to support traffic and transport management in inland navigation (Durajczyk, 2014).

RIS is an information system based on the concerted interaction of three elements: equipment, software and operators. The link between all these elements is the communication system, both wired and wireless (Durajczyk, 2014).

Among other things, the system makes it possible to increase the safety of shipping and to increase its efficiency. RIS also modernises the exchange of information between supervisors and waterway users. RIS services use common systems to link pilots, shipping companies, lock, port and terminal operators, RIS operators, and fairway authorities and emergency services. They also enable better law enforcement, collect statistical data and facilitate the calculation of port and fairway charges (Durajczyk, 2011).

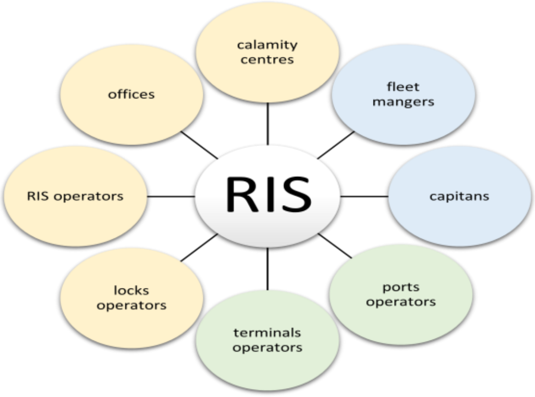
RIS service systems use common systems for ensuring connectivity of:

- Pilots,
- Transportation companies,
- Lock, port and terminal operators,
- RIS operators,
- Waterway Supervision Authorities (in Poland the Inland Waterway Authority in Szczecin and the Regional Water Management Board in Szczecin),
- Emergency Services.

And also:

- Law Enforcement,
- Collection of statistical data,
- Calculation of harbour dues and fairway charges,
- Fleet management.

Figure 3. *RIS User Diagram*



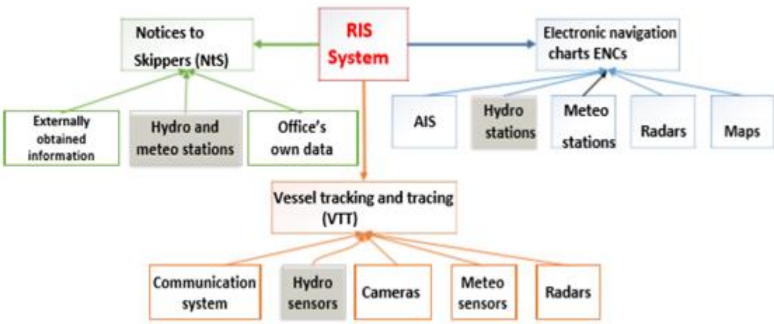
Source: *Own elaboration.*

In the diagram above, the yellow color indicates entities associated with the state, the blue color indicates the private sector and the green color indicates entities that can both be state-owned and private. This information may be collected, processed and transmitted to end users using a variety of tools and techniques. Some information may be processed by multiple techniques, and the selection of a particular technique may depend on a number of factors (e.g., time consuming, capital intensive, local considerations, cost of maintenance). Four main technologies are used to provide RIS river information services:

- Vessel traffic control system [VTT],
- Notices to Skippers [NtS],
- Electronic Ship Reporting [ERI],
- Inland Electronic Chart Display and Information Systems [Inland ECDIS].

Figure 4 below shows a diagram of the RIS system in Poland.

Figure 4*: Schematic representation of RIS*



Source: *Durajczyk 2020, p. 203.*

The RIS system has been implemented in Poland only on a short, estuarial section of the Oder River. The necessity of implementing a harmonised river information system RIS on the Lower Oder River by the end of 2013 resulted from the provisions of the Directive 2005/44/EC of the European Parliament of 7 September 2005. According to this Directive, Member States of the European Union are obliged to adapt the RIS system to all waterways of class IV and higher if they connect to other waterways of the same standard. In Poland only the lower stretch of the Oder River fulfils all these conditions, hence the obligation to implement the system.

Optionally, Member States may also implement the system on other waterways, if they consider it appropriate. Poland decided in a first step to implement RIS only on the mandatory section and only at a later stage to extend the area to other waterways.

According to the Act of 10 June 2011 amending the Act on Inland Navigation and the Act on Inland Waterway Transport the entity responsible for the implementation of the river information services in Poland is the Inland Waterway Shipping Office in Szczecin, which is a central public administration unit, subordinate to the minister in charge of maritime economy and inland navigation.

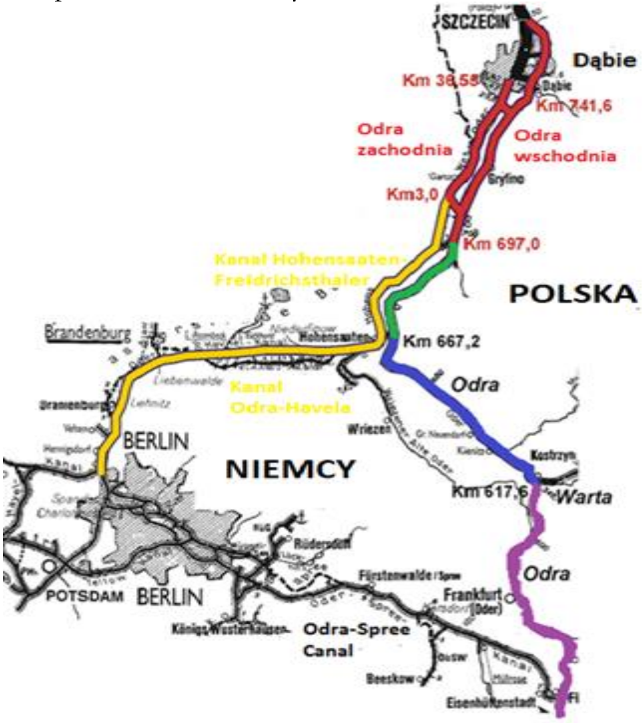
The first stage of RIS implementation in Poland was carried out within the framework of the project named "Pilot Implementation of RIS Lower Oder" co-financed from the TEN-T Fund [No. 2010-PL-70206-P] under the Decision of the European Commission of 10 December 2012 No. C(2012)9020) and assumed the implementation of RIS at the minimum level required by the Directive 2005/44/EC of the European Parliament.

3.1 Area of RIS Implementation in Poland

As a pilot project, the system has been implemented on the Lower Oder River, south of the town of Ognica and north to the borders with the marine waterways in the Szczecin Waterway Node. The RIS area includes the following waterways:

1. Lake Dabie to the border with internal sea waters - a 9.5 km long section.
2. River Odra from Ognica to the Klucz-Ustowo Piercing and further as the Regalica River to Lake Dabie - a stretch of 44.6 km.
3. Western Oder River:
    a. From the weir in Widuchowa (704.1 km of the Oder River) to the border with internal sea waters, together with side branches - a 33.6 km long section,
    b. Klucz-Ustowo Trench linking the East and West Oder rivers - a 2.7 km long section,
    c. River Parnica and Parnicki Piercing from the West Oder River to the border with internal sea waters - a 6,9 km long section.

Figure 5. *RIS implementation area of the Lower Oder River*



Source: *own elaboration based on: Wasserstrassen von Elbe bis Oder. Band 10a: Die Oder. Nagel's Nautic Verlag. Berlin 1993, p.3*

Legend:

- *The area of the pilot implementation of RIS Lower Oder (the area of the current RIS system) is marked in red,*
- *in green, first option to extend the RIS to the town of Hohensaaten,*
- *in blue colour the second variant of extension by additional 50 km to Kostrzyn,*
- *in violet colour the variant 3 is presented, which covers the whole border section of the Oder River.*

It should be noted that the Oder River in the northern section from the port of Szczecin to the mouth of the Baltic Sea at Świnoujście has the character of an internal marine road and is supervised by the maritime traffic management system - VTS.

3.2 RIS Services in Poland

The RIS system in Poland consists of the following components:

- **Inland Electronic Navigational Charts [Inland ENC],** which are produced in the latest, currently valid 2.3 standard and are available free of charge on the website. The Polish RIS Centre has a complete line for the production and distribution of electronic navigational charts, including a surveying unit equipped with a multibeam echo sounder and the necessary software for bathymetric surveys. The charts are updated when needed, and their validity (e.g., position of navigation marks) is verified by RIS operators at least once a month.

- **Notices to Skippers (NtS),** which provide information on the traffic and fairway situation, water levels, weather reports and in winter time ice reports. The information is prepared in Poland by the Regional Waterways Management Board, which is legally responsible [4] for, among other things ensuring that the beds of natural watercourses and canals are maintained in good technical condition and regulating water levels.
- **Vessel tracking and tracing - VTT,** which is used for ongoing monitoring of waterway traffic and for transmitting information to the relevant institutions and services. In Poland, in inland navigation, the skipper makes his/her own navigation decisions, therefore no navigational commands or recommendations can be given by the RIS operator.
- **Electronic Ship Reporting -** ERI, which is currently being tested. The system, via a special application, allows the ship's captain to report the voyage and provide information required by law (e.g. crew composition, cargo carried, destination port, etc.). In the future, it is being considered to introduce on the lower section of the Oder River an obligation for ships to report electronically before entering the RIS area.

a. RIS systems and equipment in Poland

The RIS system in Poland is based on the following technical solutions:

1. **The AIS system consists** of two base stations located in the northern (Ewa Elevator) and southern (Widuchowa Weir) part of the RIS Centre area.
2. The **camera system**, which includes 34 cameras (including three pan-tilt-zoom cameras), installed in critical locations requiring observation. The cameras were installed at the entrance and exit to the area covered by RIS. As there is no obligation to have AIS in Poland, they are the main source of information on vessels entering the RIS area. In addition, cameras are installed in all locations identified as potentially dangerous, i.e. on bridges and river branches.
3. **Meteorological sensor system,** which consists of 4 devices Vaisala WXT520. Devices allow to monitor wind speed and direction, precipitation amount and intensity, temperature, air pressure. The information is presented on the website of the Information Portal of the Inland Waterway Shipping Office in Szczecin and is archived, which will allow for the preparation of specialist analyses in the future.
4. A **hydrologic sensor system** that includes 14 microwave water level gauges measuring water levels at nine locations. At the five most critical locations,

[4]*Act of 18 July 2001. Water Law (Journal of Laws of 2015, item 469 as amended).*

the sensors were installed in a redundant arrangement in which a second unit provides information to the system in the event of a failure or lack of communication with the first unit.
By relating the collected values to reference values, it is possible to precisely calculate clearances under bridges, which are the most important element limiting navigation on the Lower Oder River. The software also allows you to define up to three values, exceeding which the system will automatically generate an alarm. The data is archived by the system for each location separately.

5. **DGPS corrections system** which allows to increase the accuracy of ship location to several centimetres using WGS-84 ellipsoid in inland navigation. Within the pilot implementation, an autonomous DGPS-RIS reference station has been installed, which by means of AIS installed at the Ewa Elevator location sends corrections to a second AIS base station at the Widuchowa Weir location. The system consists of two segments:
   - Segment for generating RTCM differential patches and their conversion to AIS,
   - Receive segment and monitor item quality.
6. **VHF communication system,** which enables voice communication between the ship's captain and RIS operator in the whole RIS area in Poland. The system consists of one VHF radio station installed on the Ewa Elevator. It is equipped with:
   - two radio stations,
   - two VHF directional antennas,
   - VHF monitoring receiver,
   - DSC radio.

   The VHF equipment is connected to a network interface where the signal is digitised and sent to a server at the RIS Centre.

4. Automatic Bridge Clearance Measuring System

One of the most frequent situations affecting safe navigation is the contact of a transport unit with bridges within Szczecin city limits. The most frequent reason for such incidents is a wrong estimation of the safe height for passing of an inland vessel connected with the vertical changes of water fluctuations. The captain of the vessel relies only on the manual readings of the water level gauges, where the accuracy can be estimated above 10-20cm.

In view of the above, the Inland Navigation Office in Szczecin, within the EMMA project, developed and implemented a system for automatic indication of the safe clearance under the bridge. As part of the pilot project, the system for indicating the safe clearance under bridges for inland waterway transport units was implemented on two bridges. As part of the project, measurement and telemetry sensors were installed, allowing for very accurate clearance measurement. Another very important element of the system are information boards displaying the current clearance under the bridge. All strategic data will be collected, analysed and managed by the RIS Centre operators. The target group benefiting from the pilot implementation of the system are the vessels travelling on inland waters, both commercial and tourist vessels as well as the waterway administration.

The pilot system implemented on two Szczecin bridges - Długi and Cłowy - consists of three elements:

1. **control devices and telecommunication modems -** located in a cabinet with dimensions 1000x800x300, which is installed on the bridge
2. **Hydrological** sensors, taking measurements, fixed on the steel structure of the bridge in a way that is both permanent and not visible from the outside
3. **LED Displays -** two LED display devices, each with an individual data readout from the System Headquarters. Both devices display a measurement or other preset content. This content can be different for each display. The display is equipped with bird protection and a removable information board with the Investor's data.

The Bridge Safety Clearance Indication System provides real-time monitoring of safe clearance, water level and clearance values on LED displays. The water level is measured by a radar sensor. The device performs measurements at set time intervals and the collected data are sent via GPRS communication to the System Central.

After sending the data to the System Headquarters in the DataManager software, the measurements are compared and the smaller measurement is sent for display on the LED displays. Additionally, each of the components of the measurement system has a SIM card of a different operator, which provides an additional channel of data transmission. These solutions enabled redundancy, which was used not only to ensure data continuity but also to increase the measurement reliability. The acceptable divergence of measurements should not exceed 5 cm. One of the tasks of DataManager is also direct communication with water level measurement point and LED display. This communication takes place in open APN and is coded.

For network security, each peripheral device connecting using GPRS network has a SIM card with a static IP number. Any attempt to connect to the server from other IP addresses than those from the allowed pool is ineffective. Another task of the DataManager program is to operate in the database. The program stores all measurements in a database. The term "all measurements" includes the measurements taken by the radar sensor, as well as the operating parameters and configuration data of the water level measuring point device and LED displays. The collected data are available to external systems via a Web Service. The web site is one of the components of the system and although it is embedded on server 2 it is treated as an "external system" and connects for data to the System Headquarters using the Web Service. This solution has two main advantages:

- The site can be exported to any other server,
- The page does not load the communication of the server no. 1 on which the communication with devices and the operation of the system control program (DataManager) takes place.

The Bridge Safety Clearance Indication System must meet a number of requirements for how to measure, where to measure, the parameters of the measuring device, measurement of the current water level, display at the measurement site with transmission to a central server collecting telemetry data and displaying as a screen with information from all locations.

In order to increase the reliability of the system, the system has been equipped with an alternative power source in the form of a solar panel and batteries, sustaining the work of the measuring system for a long time, and in the case of the display - for the time necessary to sustain the display of the measured information. The system allows the use of a network interface for data transmission to a data collection server. However, data security requires the data to be stored in the server room of the Inland Waterway Authority. Each component of the measurement system has a SIM card of a different operator, which provides an additional channel for data transmission.

The system has two level measurement sensors at each measuring point, thus providing measurement redundancy and eliminating erroneous results

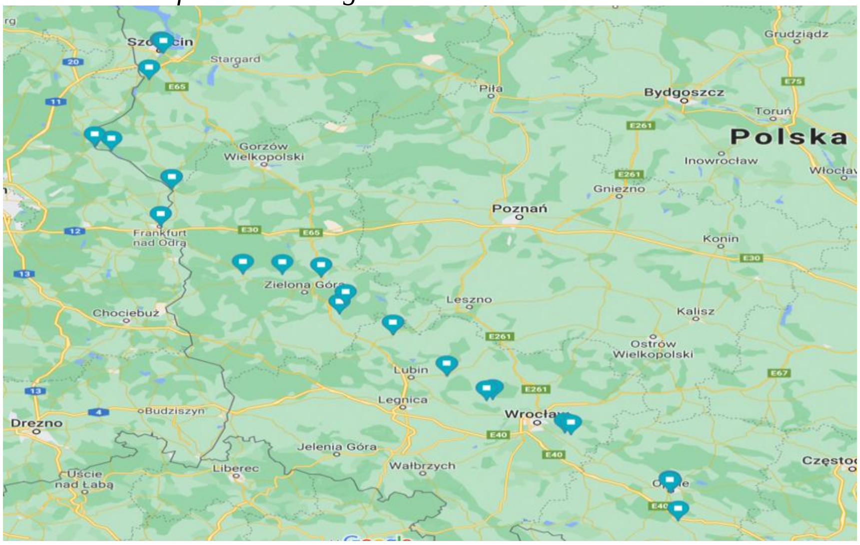
5. Possibility of Implementing a Clearance Measuring System under Bridges

The purpose of this paper is to analyze the possibility of implementing a system for measuring the clearance under bridges along the Oder River from Kędzierzyn-Koźle to the Szczecin Water Junction on bridges that may potentially pose the greatest difficulties. There are 61 bridges in this section, of which 28 at WWŻ have a clearance of less than 5.25 m, i.e., according to Polish regulations, the minimum value allowing navigation (Table 1). 14 of these bridges may be considered unsafe because their clearance at WWŻ is less than 4.00 m. It was these bridges that were selected for implementation of the clearance measuring system in the first place. The location of these bridges on the Oder River is shown in Figure 7.

Depending on the implementation variant adopted, the costs of a comprehensive clearance measurement system will vary significantly. In the case of the basic implementation, in which data are collected and published only at the location of equipment, due to the possibility of using universal solutions (equipment mountings on bridges, batteries and photovoltaic devices) the costs are relatively small. The cost of implementing the system for measuring the clearance under bridges at one measuring point is 81 000.00 PLN net, so 99 630.00 PLN gross. It is constant, regardless of the number of bridges on which the system is to be placed. Therefore, the total implementation costs on the selected bridges are as follows:

81 000.00 PLN x 29 [bridges] = 2 349 000.00 PLN à net cost
99 630,00 PLN x 29 [bridges] = 2 889 270,00 PLN à gross cost

Figure 7. *Location of selected bridges on the Oder River*



Source: *Own study based on [maps.google.com, accessed 11.05.2021].*

Table 1. *Bridges on the Oder Waterway with a clearance at WWŻ less than 5.25 m*

L.P.	BRIDGE	KM OF WATERWAY	RIVER	CLEARANCE AT WWZ [M]
1	Railway bridge in Krapkowice	126,17	Oder	4,58
2	Road bridge in Opole - Bolko Island	150,59	Oder	4,34
3	Railway bridge between Wroclaw and Krakow	151,25	Oder	3,71
4	Piast Bridge	152,12	Oder	3,7
5	Bridge of Siberian Memorials	152,54	Oder	3,96
6	Road	216,42	Oder	3,72
7	Railway bridge in Czernica	230,70	Oder	4,55
8	Railway bridge Brzeg Dolny	283,20	Oder	5,21
9	Bridge of Freedom - 4 June	286,45	Oder	4,13
10	Railway bridge Ścinawa	331,60	Oder	4,39
11	Road bridge Ścinawa	331,90	Oder	4,01
12	Bridge of Tolerance	392,90	Oder	4,83
13	Railway Bridge Glogow	393,30	Oder	3,90
14	Road bridge Nowa Sol	428,80	Oder	4,73
15	Railway bridge States	437,50	Oder	3,98
16	Road bridge Cigacice	470,70	Oder	3,72
17	Railway bridge in Nietkowice	490,50	Oder	3,79
18	Road bridge Krosno Odrzańskie	514,10	Oder	3,80
19	Long Bridge	35,95	Western Oder	3,40
20	Railway bridge PKP Main Railway Station	35,59	Western Oder	3,79
21	Road bridge Gryfino	718,18	East Oder	5,17
22	Harbour Bridge	4,00	Parnica	3,82
23	Railway bridge	4,45	Parnica	1,89

24	Road bridge Osinów Dolny	662,30	Border Oder	5,09
25	Railway bridge Siekierki	653,90	Border Oder	4,14
26	Railway bridge Kostrzyn	615,10	Border Oder	3,67
27	Road bridge Kostrzyn	614,90	Border Oder	4,31
28	Road bridge Słubice	584,20	Border Oder	5,15

Source: *Own study.*

A much bigger challenge is to implement a full system in which the information collected from the devices at the individual locations is continuously sent to the RIS Centre and then published on dedicated websites, and in which the RIS Centre operator has the possibility of remote management of the displayed information (e.g. the possibility to switch off the display in case of doubts about the correctness of the performed measurements).

The cost of full implementation, in the minimum variant, should be estimated at about 9-10 million PLN, assuming that the cost of building one mast/tower location is estimated at 500,000 PLN plus the cost of power connections.

5.1 Benefits of System Implementation

It is not easy to make a financial assessment of such a project in the short term. Such infrastructure upgrading investments build the credibility and viability of inland navigation. The installation of bridge clearance sensors can warn of insufficient clearance and thus be able to prevent potential incidents, damage and collisions. This will undoubtedly bring significant economic benefits in the long run, and a modern and safe infrastructure means the popularity of this type of transport and tangible benefits for businesses.

This investment fits perfectly with the work schedule of RIS, which is the main operator of the functionality of this task, as well as many others that improve efficient navigation. The overall core benefits of RIS include:

- more efficient use of units - use of accurate and up-to-date information about the waterway available on the Internet allows for better fleet management (optimization of staff work and fleet management based on current information), as well as more careful voyage planning.
- Reduction of fuel consumption per transport unit - information on current clearances under bridges and thus also on transit depths will allow full utilisation of the fleet thanks to information on the maximum permissible draught.
- Increased safety - RIS services offer skippers a comprehensive overview of the current traffic situation on the waterways. Well-informed skippers can take navigational decisions appropriate to the current situation. Consequently, knowledge-based navigational decisions lead to fewer incidents, accidents and casualties. This is especially true when transporting dangerous cargo.

6. Conclusions

For commercial users of waterways in Poland, draught limitations and clearance levels under bridges are a significant problem. In the summer season frequently recurring droughts cause very low water levels and effectively impede navigation. On the other hand, excessively high water levels, which often occur in spring, intensify the constrictions, which are bridge structures with low clearance. As the water rises, a sudden flood wave reduces the clearance of the bridge to a level that makes it impossible to cross freely and safely.

The ship's draught depends on the weight of the loaded vessel. The implementation of a bridge clearance measurement system is part of the technological development of inland navigation and increases its profitability, safety, predictability, provides data for long-term planning to prevent floods and droughts, encourages entrepreneurs to integrate this mode of transport into their transport chains.

Generally, operators aim to maximize the payload of the vessel and thus maximize the draft in the water. However, often a vessel is fully loaded on the way to port and is not fully loaded on the return trip. Therefore, one of the most common situations affecting the safety of navigation is the contact of empty or partially unloaded vessels with one of the bridges, caused by misinterpretation of the reading of non-digital water gauges. The most common cause is the misjudgment of the vessel's passage height, related to vertical water level changes caused, for example, by waves. When the skipper relies solely on manual readings of the water level gauges, the accuracy varies within +/- 10-20 cm.

Solving this problem would not only help improve safety, but also would allow for more flexible vessel loading: Vessel loading procedures can be adapted to the latest waterway conditions, thus allowing bridges to be crossed in the best possible way with both maximum and minimum cargo. Thus, the use of information that takes into account the current value of the clearance under the bridge will have a positive impact on navigation safety and on logistics (better route planning).

The use of information boards with the current clearance under the bridge will first of all increase the safety of navigation. Another important element is the aspect of logistics itself and shortening the time of a transport vessel's journey from A to B. Thanks to the knowledge of the passage conditions under the given bridge, the captain, shipowner, forwarder or logistician will be able to plan the ship's route in a different way, which will affect the costs and safety of transport. The knowledge of the current clearance may also influence the process of loading the vessel and adjusting the height to the expected conditions.

- Improvement of project outputs, improvement of the reliability of transport services between DE and PL by increasing the quality of RIS services provided.

- To improve the quality of VTS services by using dynamic bridge clearance information. By supporting the development of interfaces and adding measurement instruments to create useful solutions supporting RIS services.

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