Assessing the impact of climate change and weather conditions endangering inland waterway navigation

Patrik Hegyi, Ahmed Jaber, Dávid Földes, Bálint Csonka, Dahlen Silva and Csaba Csiszár

***Abstract*— Inland water transportation has been long-recognized as an environmentally friendly and efficient transportation mode. The problem is that the availability and efficiency of inland water transportation are heavily influenced by droughts, floods, and extreme weather conditions, and climate change will worsen it. The influence of these factors on inland waterways can be mitigated by soft measurements, such as providing information services. This study aims to reveal the most influential weather conditions and relevant information service functions covering shipment, as well as loading and storage at ports. Hence, deep interviews and an online questionnaire were conducted with relevant stakeholders. The most influential weather conditions were low water for shipment, intense precipitation and storm for loading, and high water for storage. The transportation planning could be improved by more than 1-week forecast on low water, a 5-day forecast on high water, floods, and heatwaves, and a 2-day forecast on intense precipitation, wind, and fog. The results highlight the main development areas and functions for information service developers.**

***Index Terms*— climate change, inland waterways, IWW, information services, weather**

I. Introduction

INLAND waterways (IWW), consisting of rivers, lakes, canals, and backwaters, are one of Europe's most significant transport systems [1]. IWW transport is long-recognized as the most CO_2-efficient transportation mode besides rail [2]. Accordingly, the European Commission expressed its commitment to the IWW transportation in the European Green Deal [3], in the Zero Pollution Action Plan [4], in the Sustainable and Smart Mobility Strategy [5], and in the NAIADES III [6], shifting freight transport by road to inland navigation and become more resilient to changes. In the Netherlands, IWW freight transportation already has a significantly higher modal share (43%), but the expense of rail transportation and the EU average is very low (6%) [7].

The problem is that the ability to operate and the reliability of services highly depend on the weather in IWW transportation. Furthermore, the sector faces new challenges because of climate change, like heavy rainfalls, floods, and longer drought periods [8], [9]. In addition, IWW transportation usually does not provide door-to-door services; therefore, it requires a multimodal approach to integrate IWW transportation into the supply chain. In general, measures to overcome the challenges are separated into changing the vessel or introducing river regulations. The new, lighter material and small vessels belong to the first category, while additional barrages and storage basins belong to the latter category [10]. Since the operational activities strongly influence each other, the need for efficient communication arises. To tackle climate change, resilience rules help maintain the operation of an inland navigation network during extreme conditions such as floods and drought [11]. The information layer helps connect the system's stakeholders and supports efficient communication and high-quality information services, such as real-time vessel monitoring. However, what an information service should focus on mitigating weather-related impacts is under-researched.

In this paper, we analyze IWW transportation, focusing on the available information services and current problems through deep interviews and an online survey. The analysis covered traffic management, infrastructure management, and logistics service management. The aim is to determine end-user needs and good practices, reveal and identify the long-term effects of climate change and develop the proper information service-related answers.

The structure of the paper is as follows: Section II contains a review of the relevant literature. In Section III, a description of the methodology used is provided. In Section IV, the results of the interviews and questionnaire survey are described and discussed. Finally, the conclusions are drawn in Section V.

II. Literature review

The literature review was conducted with a focus on weather, climate change, and information systems.

Extreme weather events relevant to IWW transport are low-water events (drought), high-water events (floods) as well as ice occurrence [12]. Droughts have the most disruptive impacts on inland waterways; they can severely disrupt inland waterway navigation services by reducing water levels either to a completely unseaworthy levelto a level that obliges

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operators to reduce vessel loads [10], [13]. Long periods of low water levels may increase transportation costs due to the limitation of the cargo capacity [10]. Furthermore, shallow water may force the exchange of large vessels to small ones as the latter are less affected [12]. Higher than normal water levels may affect inland navigation, while stronger and more adverse currents may increase the likelihood of accidents and travel times [10]. In addition to water levels, ice can also disrupt inland waterway operations, causing damage to the infrastructure and suspending navigation [12], especially in slow-flowing rivers; for example, navigation on the Danube was interrupted for several days in the winter of 2005 and 2006 due to ice [1].

Climate change worsens weather impacts [14], and extraordinary events caused by sudden, heavy rainfall and long drought period can occur in the same year [15]. The impact is harmful despite the decreasing number of days with low water levels because of an increase in the discharge levels due to an earlier melting season benefitting the operations in some regions [1].

Several information sources are available for IWW users. Digital information services that foster IWW's efficiency and sustainability are considered essential for improving its attractiveness and reducing greenhouse gas emissions in the transportation sector. However, IWW operators do not have sufficient insight into the extent of information on available services [16]. Having a single point of information provides several advantages: alleviates repetitive searching for information, saving time; easiness of updating and implementation of strategies against fraud, increasing user's trust; efficiency in complying with regulations and lower investments than maintaining many sources; simplified training of navigators, pilots, and other employees; increase the efficiency of the IWW transport, improving competitiveness [17]. The River Information Services (RIS) are categorized into many information levels (e.g., traffic information, logistics management information) connected to multiple users and levels of operation. In RIS, the personnel evaluate the data (traffic, weather, water level, etc.) and decide which information should be dispatched to multiple users. Human errors might occur, and the information received might not be appropriate as decisions are based on personal experience/judgment and similar business situations. Therefore, using an automated system based on artificial intelligence may increase the entire system's efficiency [18].

Data from general or other specific meteorological networks are usually not representative of waterways' local weather - especially in shallow fog patches of river origin or local low-level wind channels due to relief – because a very limited number of measuring stations are installed near riverbanks. Therefore, the weather forecasts do not consider the local conditions of the IWW [19]. Location-related information types are of little demand and have lower importance ratings, which may reflect a weak interdependency with operational planning. Functionalities that address planning issues received strong support from the respondents, while the provision of real-time bridge clearance information, as well as electronic port announcements, have been stated as the most important [16].

In summary, climate change may increase the frequency and intensity of extreme weather occurrences, which may increase transportation costs, suspension of operation, and damage to the infrastructure. In many cases, general or other specific meteorological networks are not representative of IWW users; therefore, there is a need for initiative solutions to reduce uncertainty and fulfill IWW users' needs.

III. Methodology

Deep interviews and an online questionnaire survey were conducted to reveal stakeholders' insights on IWWs and identify the end-user needs regarding an information service. The key topics of the interviews and the questionnaire survey were the following:

- operational difficulties,
- other difficulties,
- impacts of weather,
- impacts of climate change,
- information system and service development (general remarks, available services, suggested services).

The questionnaire survey was conducted to reach a wider audience covering infrastructure operators, transportation and logistics operators, and other organizations such as meteorological companies, research institutes, and NGOs. It included open and closed question types. Respondents evaluated the frequency and duration of weather conditions. The questionnaire covered the following weather conditions:

- low and high water levels,
- fog,
- icing,
- intense precipitation,
- strong wind,
- heatwave.

Three impact areas were considered: shipment, loading, and storage. Respondents put the impact areas in order of relevance in IWW transportation. Finally, the following consequences were considered:

- delay,
- blocking the IWW,
- vessel damage,
- reduced capacity utilization of the vessel,
- higher resource requirements,
- spoilage of goods,
- loss of goods,
- additional maintenance,
- blocked cranage,
- blocked cargo slide,
- stuck cargo,
- longer loading time
- loss of goods,
- cargo eroded,
- storage facility damage
- impassable depot,

- transformer damage (power grid),
- underutilization of storage facilities.

Questionnaire respondents had to answer whether there is a connection between a weather condition and a consequence considering the cause-and-effect relationship.

To estimate the impact of a weather condition on IWW transportation, the weighted significance of weather conditions is calculated considering the relevancy of an impact area and the relationship between weather conditions and consequences. The steps are as follows:

1. Converting average relevance to a p_k percentage scale (1), where r_k is the average relevancy of impact area *k*.

$$p_k = \frac{r_k}{\sum r_k} \cdot 100\ [\%] \quad (1)$$

2. Converting the number of respondents who answered, there is a connection between weather condition *i* and consequence *j* in impact area *k* ($n_{i,j,k}$) into a percentage scale for each impact area, expressing the frequency of weather condition *i* causes consequences in impact area *k* (2).

$$q_{i,k} = \frac{n_{i,j,k}}{\sum n_{i,j,k}} \cdot 100\ [\%] \quad (2)$$

3. Calculating the weighted significance of weather condition *i* (3).

$$w_i = \sum_k p_k \cdot q_{i,k} \quad (3)$$

Questions about the information system covered the channels (radio, mobile phone, online application) and used services (meteorological forecast, water level, traffic information, and port information). Regarding the proposed information service, respondents could give the importance of the following functions:

- hourly notification on water level,
- automatic, location-based weather information,
- automatic, location-based traffic-related information,
- information about short-term bottlenecks,
- information about the predicted available capacity of ports, border control stations,
- visualize the signaling during navigation,
- society-based information collection and sharing.

The importance of given information services and functions was evaluated on a 0-5 scale.

IV. Results and Discussion

A. Deep interviews

Representatives of the following organizations accepted our invitation for the interviews. Academy and research institutes:

- Danubius University of Galati (RO),
- University of Liege (BE),
- National Research-Development Institute for Marine Geology and Geoecology – GeoEcoMar (RO).

Port logistics companies:

- Dunatár Ltd. (HU),
- Ferroport Ltd. (HU),
- Human Shipping Ltd. (HU),
- MAHART Container Center Ltd. (HU).

NGO:

- Hungarian Federation of Danube Ports (HU),
- Inland Waterways International (Europe),
- National Radio Emergency Call and Infocommunication Associate (HU),
- Romanian River Transport Cluster (RO),
- WWF (Central and Eastern Europe).

Governmental:

- Galati Lower Danube River Administration (RO).

IWW operator:

- Canal & River Trust (UK).

Representatives shared their everyday experiences, opinions, and expectations during the free and unstrained 30-60 min discussions. The main statements are as follows.

The low water level has been occurring more and more frequently and for more extended periods over the past 20 years and was found to be the biggest challenge for IWWs without water level control. Low water levels may make shipping impossible or inefficient for several months a year. Therefore, investment in waterway infrastructure, such as dams, is essential in increasing the modal share of IWW transportation. In line with that, clients preferring road and rail transportation appreciate their reliability and availability. High water levels require more engine power and careful mooring because of the higher water velocity. However, the high water level is rare these days. Casual, sudden flash floods have severe impacts which cannot be reliably predicted. Also, the flood could not be mitigated, but the evacuation plan could be improved. Water levels data are precise and reliable, but flash flood alert is missing.

In cold weather, the container may "freeze" in the vessel, which hinders loading. However, such causes are rare or have little effect. Similarly, icing is losing its relevancy because of climate change. A strong wind (above 40 km/h) may cause problems in navigation and cranage operation, but the average number of days with strong wind is only around 20 days a year. Other extreme weather conditions have little impact on the operation because of their rare occurrence.

Sediment formation causes a problem in ports. Sediment is deposited in some sections/entrances of harbors, and navigability is compromised and limited.

Currently, the information service is fragmented. An integrated information system is needed, as well as improved cooperation between the administration, national agencies, shipping service providers, etc. The vessels can be followed in real-time; however, in many cases, the exact time of arrival is difficult to estimate. Therefore, it is challenging to plan the work scheduling of loading.

B. Questionnaire

The questionnaire was shared among the relevant stakeholders between November and December 2022, and 27 respondents answered the questions. Respondents are mainly transport and logistics operators, a few are infrastructure managers, and some of them work in the related sector. One-third of the total respondents are representatives of carrying companies; thus, one-tenth of the respondents are vessel operators, loading companies, or authority/governmental institutes. The respondents' service area covers the European Union and most of the European Economic Area.

The average relevancy of shipment, storage, and loading is 34%, 28%, and 37%, respectively (step 1). The relative impact of weather conditions is given for each impact area in Fig. 1 (step 2).

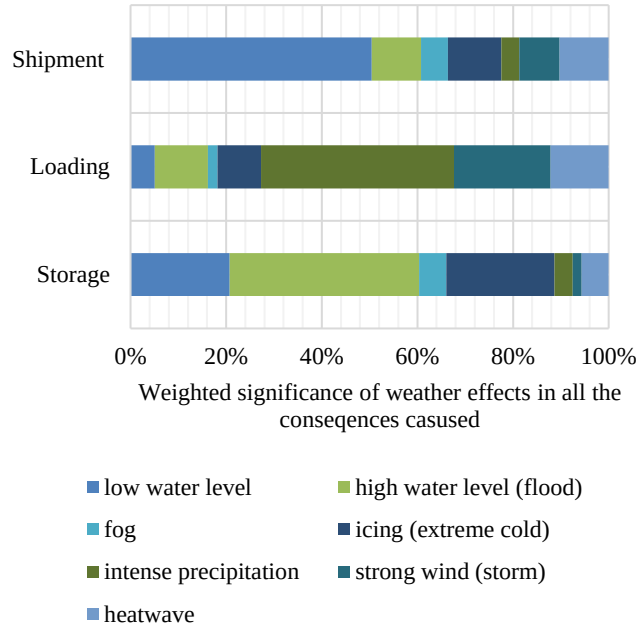

Fig. 1. Weighted significance according to impact areas

The low water level was the most influencing weather effect during shipment, causing reduced capacity utilization of vessels. Furthermore, the low water level significantly causes delays, vessel damage, and higher resource requirement. The strong wind mainly causes the loss of goods, and heat waves cause the spoilage of goods.

Intense precipitation and strong wind were found as the most influencing weather conditions during loading. Extreme precipitation is the primary cause of the loss of goods and longer loading time, but it affects blocked cargo slides. However, intense precipitation has a low occurrence. The strong wind mainly blocks cranage. Heat waves and high-water levels have a moderate influence.

The flood and icing were found as the most influencing weather effect during storage. They damage the cargo and facilities.

The relative impact of weather conditions on IWW transportation is given in Fig. 2 (step 3).

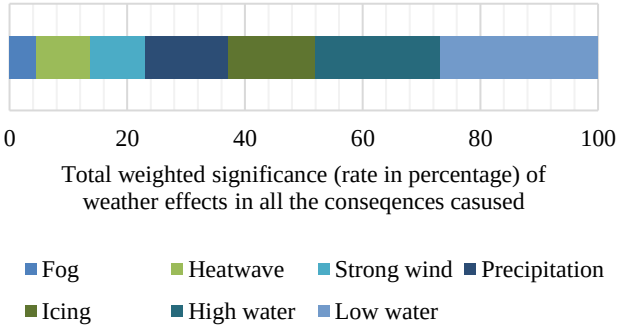

Fig. 2. Total weighted significance

It was found that the low water level is the most crucial factor in the whole IWW system; the high water level comes in second place. This indicates the high impact of the water level. On the other hand, the fog and the heatwave were ranked in the last positions. Though the expected duration of icing, intense precipitation, and strong wind are low, their significance is high. Accordingly, information provision and prediction of these effects are also necessary.

According to the respondents, the most used communication channel is an online application, but pure mobile phone-based communication is also widespread. Radio-based communication is only used by vessel operators.

The used information systems and services by the respondents:

- meteorological forecast
- water level information
- water traffic information
- port information

The respondents are the most satisfied with the water level information. High satisfaction is proved for GPS-based navigation, internet availability, and meteorological forecast. The lowest satisfaction is with the water traffic and port information.

For strategic planning, several respondents highlighted that an information service that integrates multiple data sources holistically is needed. A notable portal was mentioned (danubeportal.com), which can be a good basis for an integrated service, but the accuracy and variety of the information provided should be higher. Other respondents committed to establishing obligatory sail plans for all transits in conjunction with waterway traffic control services. Loading companies express their attitude towards properly estimated traffic data. However, a Hungarian carrying company stated that all the necessary information is available; there is no need for information service developments. Forecasting weather effects and maintenance events was noted as an essential service for tactical planning and operational control and planning.

The most important information services would be automatic, location-based weather information, information about short-term bottlenecks, and automatic, location-based traffic-related information. Moderately important functions are the signal visualizing during navigation, the information about the predicted available capacity of pots and border stations,

and the information collection and recording by users along waterways. Respondents evaluated the time horizon of forecast services accordingly:

- more than 1-week forecast: low water level, icing,
- 5-day forecast: floods, high water level, and heat waves,
- 2-day forecast: strong wind, intense precipitation, and fog.

V. Conclusion

The main weather and climate-related effects on IWW and possible information services mitigating their impacts were assessed using deep interviews and a questionnaire survey. We found as a key finding that low water level is the biggest challenge for IWW transportation which is further worsened by climate change. Water level control is necessary to improve transportation reliability, availability, and efficiency of IWWs. Otherwise, the modal share of IWW transportation will decrease. A lot of information services are already available; however, these services are fragmented, and there is a need for an integrated service. GPS-based navigation and the water level forecast are reliable, but other IWW transportation-related information services may be improved to achieve better service quality. Icing should be forecasted more than 1 week before the occurrence to mitigate the damages and better estimate the travel time. Floods, high water, and heat waves should be predicted 5 days before occurrence to reduce damages. In addition, strong winds, heavy precipitation, and fog should be forecast 2 days in advance to plan the loading of ships in ports and improve navigation. In addition, port-related and traffic information is lacking; related information services are important. Based on the results, we plan to elaborate on the conceptual and data model of an integrated IWW transportation information service.

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References

[1] A. Christodoulou, P. Christidis and B. Bisselink. (2020, May). Forecasting the impacts of climate change on inland waterways. *Transportation Research Part D.* [Online]. 82, p. 102159. Available: https://doi.org/10.1016/j.trd.2019.10.012

[2] A. Klein, D. Hilster, P. Scholten, L. van Wijngaarden, E. Tol and M. Otten. (2021, Feb.). STREAM Freight Transport 2020 - Emission of freight transport modes. CE Delft. [Online]. Available: https://cedelft.eu/publications/stream-freight-transport-2020/

[3] European Commission. (2019, Dec.). The European Green Deal. Brussels, BE. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0640&from=EN

[4] European Commission. (2021, May). EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'. Brussels, BE. [Online]. Available: https://ec.europa.eu/environment/pdf/zero-pollution-action-plan/communication_en.pdf

[5] European Commission. (2020, Dec.). Sustainable and Smart Mobility Strategy - putting European transport on track for the future. Brussels, BE. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789

[6] European Commission. (2021, Jun.). NAIADES III: Boosting future-proof European inland waterway transport. Brussels, BE. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2021:324:FIN

[7] T. Bayer, N. Kriedel, L. Roux. (2020). Market Report 2014-2019 - Main features and trends of the European Inland Waterway Transport sector. Central Commission for the Navigation of the Rhine. [Online]. Available: https://www.ccr-zkr.org/files/documents/ompublicationssp/Market-report-2014-2019_Web.pdf

[8] E. Byers, M. Gidden, D. Leclere, J. Balkovic, P. Burek, K. Ebi, P. Greve, D. Grex, P. Havlik, A. Hillers, N. Johnson, T. Kahil, V. Krey, S. Langan, N. Nakicenovic, R. Novak, M. Obersteiner, S. Pachauri, A. Palazzo, S. Parkinson, N. D. Rao, J. Rogelj, Y. Satoh, Y. Wada, B. Willaarts and K. Riahi. (2018, May). Global exposure and vulnerability to multi-sector development and climate change hotspots. *Environmental Research Letters*. [Online]. 13, p. 055012. Available: https://doi.org/10.1088/1748-9326/aabf45

[9] M. G. Grillakis (2019, Apr.). Increase in severe and extreme soil moisture droughts for Europe under climate change. *Science of The Total Environment*. 660, pp. 1245-1255. Available: https://doi.org/10.1016/j.scitotenv.2019.01.001

[10] A. Scholten, B. Rothstein. (2016, Nov.). Navigation on the Danube - Limitations by low water levels and their impacts. Joint Research Centre. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/handle/JRC104224

[11] G. Desquesnes, H. Nouasse, G. Lozenguez, A. Doniec and E. Duviella, "A Global Approach For Investigating Resilience In Inland Navigation Network Dealing With Climate Change Context," in HIC2016., Incheon, KOR, 2016, pp. 718-725.

[12] J. Schweighofer. (2014, May). The impact of extreme weather and climate change on inland waterway transport. *Natural Hazards*. [Online]. 72, pp. 23-40. Available: https://doi.org/10.1007/s11069-012-0541-6

[13] A. Christodoulou, H. Demirel. (2018, Jan.). Impacts of climate change on transport - A focus on airports, seaports and inland waterways. Joint Research Centre. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/handle/JRC108865

[14] S. A. Némethy, A. Ternell, L. Bornmalm, B. Lagerqvist and L. Szemethy. (2022, Jun.). Environmental Viability Analysis of Connected European Inland–Marine Waterways and Their Services in View of Climate Change. *Atmosphere*. [Online]. 13(6), p. 951. Available: https://doi.org/10.3390/atmos13060951

[15] R. M. Kirovné Rácz and A. Márton. (2020, Apr.). Evaluation of Disaster Management Tasks Related to Hydrological Extremes. *Hadmérnök*. [Online]. 15(4), pp. 97-106. Available: https://doi.org/10.32567/hm.2020.4.7

[16] P. Specht, J.-N. Bamler, M. Jovic and N. Meyer-Larsen. (2022, May). Digital Information Services Needed for a Sustainable Inland Waterway Transportation Business. *Sustainability*. [Online]. 14(11), p. 6392. Available: https://doi.org/10.3390/su14116392

[17] F. Andritos. (2016, Dec.). eIWT: Electronic tool for Inland Waterways Transport: Requirements. Joint Research Centre. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/handle/JRC102516

[18] K. J. James, V. V. Shenoy, M. Bhasi and C. G. Nandakumar. (2020, Mar.). Automated ICT Systems in Inland Waterways by Developing a Multiflow River Information Services System. *International Journal of Advanced Research in Engineering and Technology*. [Online]. 10(2), pp. 389-402. Available: https://ssrn.com/abstract=3536127

[19] S. Sárközi. (2010, Jun.). Solutions for supplying meteorological information to inland waterways. Presented at EIWN. [Online]. Available: http://www.kbsz.hu/j25/dokumentumok/EIWN-paper_Sarkozi_MET_v5.6.pdf