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The Use of the DEMATEL Method to Analyze Factors Influencing the Usage of Inland Waterway Transport

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ABSTRACT: The article presents the results of the DEMATEL method (Decision Making Trial and Evaluation Laboratory) method. The method had been used to identify and analyze cause and effect relationships between factors that influence the use of inland waterway transport. The author took into account interactions between seven factors. The factors were: (1) accessibility and condition of ports, transshipment infrastructure, shipyards, and service areas, (2) operating parameters of the linear infrastructure (waterways and locks), (3) technical condition of the fleet, (4) human errors committed by crew, infrastructure operators, and/or decision makers, (5) climate and weather conditions (floods, droughts, wind, ice, groundwater level), (6) financing the water transport system - repairs, ongoing maintenance of infrastructure; subsidies and discounts for shipowners, (7) availability of information (e.g. navigation messages), method of data collection and distribution, communication and promotion of inland navigation. The analysis based on the DEMATEL method used the survey conducted among Polish experts in the field of inland waterway transport. The results of the analysis show that the most influencing factor is financing, and the most important cause influencing inland waterway transport is climate.

1 INTRODUCTION

The development of inland navigation is a current topic due to the increasing volume of transport (and the consequent congestion on roads and the use of capacity on railway routes) and due to the growing environmental requirements related to the reduction of harmful emissions into the environment.

In the European Union, the average share of inland waterways in goods transport in 2021 was 5.4%, while in Poland it was 0.1% [1]. The system of inland waterways in Poland is consistent with the course of basic cargo routes. Unfortunately, this benefit is significantly limited due to the systematic deterioration of navigation conditions on Polish waterways.

According to [1], the length of navigable routes in Poland remains at a constant level. The number of ships registered in the country also changes slightly. However, the fact that among the cargo ships (barges, pushers, tugs) registered in Poland, only one barge was built after 2010 is worrying.

Navigational conditions, especially transit depths, are typically a Polish problem. Due to the small number of kilometres of international-class inland waterways, the declared depth values do not allow for transport by ships with a draught of more than 1.8 m. This could be mitigated by more frequent sailings by lower-drawing vessels. Unfortunately, the second important problem is the variability of navigation conditions. This results, among others, from the lack of waterway cascade in most rivers, but also insufficient maintenance works. Both of these phenomena are strongly related to outlays on fixed assets for water management. And these, although in 2021 they increased by about 20% compared to 2020, are still insufficient. It is also incomprehensible that expenditures on the categories 'water reservoirs and falls' and 'flood embankment and pump station' increased by about 50% each, while regulation and management of rivers and streams' received more than 30% less. [1]

Due to the negligible share of inland water transport in the modal split of inland freight transport in Poland, it is worth analysing what is the factor that has the greatest impact on the situation.

The condition and development of inland navigation in Poland is currently the subject of interest of many researchers. The possibilities for development and analysis of the current state of Polish inland waterway transport are described in [2, 3, 4 and 5].

The issues of financing inland navigation were considered, among others, by [6], concluding that financing infrastructure is one of the most important barriers to its increased use. The assessment of the activities of the government administration in the implementation of statutory tasks related to the development and functioning of inland navigation in Poland, including financing issues, was described in [7]. Financing was also one of the risk factors affecting the implementation of inland waterway transport, described in [8]. This publication listed groups of adverse events that correlate with factors affecting the carriage of goods using inland navigation.

Economic issues are also mentioned in [9] as one of the factors that affect container shipping through inland waterways. This article also highlights the importance of infrastructure, including ship handling facilities (shipyards and ports).

[10] raises the issue of navigation parameters, their values and variability, thus referring to the condition of the linear infrastructure, but also to the impact of climate on this state of affairs. The issues of variability of weather phenomena over the years and their impact on navigation conditions are also presented in [11]. Climate is considered an important factor influencing sustainable and safe inland navigation also by [12].

Issues related to the state of the fleet are addressed in two ways. In the risk analysis already mentioned, as a factor determining the occurrence of undesirable events [8] or a factor affecting the use of shipping [9], but also in publications relating to the use of technology [e.g. 13, 14]. A ship and its technology affect safety, which is also described in [15] where the newest technology, virtual reality, supports navigation in shallow water, so that the sailor will not land.

The influence of people and especially human errors on the execution of the transportation process using inland waterways is mentioned in [8 and 12].

Errors and mistakes can be reduced by providing information. This issue is covered by, e.g. [11 and 16].

The scale of interest in the development of inland navigation in Poland shows that the topic is current and still requires a lot of analysis. In this publication, the proposed approach to the topic of inland waterway transport development by indicating the most important factors that condition this development has been presented.

2 RESEARCH METHODOLOGY

The research aimed to select factors that influence the use of inland waterway transport, to analyse cause and effect relationships between these factors, and to point out which of these factors influence the use of inland waterway transport the most.

Therefore, the adopted methodology includes four basic research steps.

The first (chapter 3), to select the factors that will be subject to further analysis, unstructured face-to-face interviews with two experts were conducted. The interviews did not include any specific form or list of factors that influence inland waterway transport to be selected, but were in the form of brainstorming based on the knowledge and experience of the respondent.

Based on the indicated factors, a list of seven factors influencing the usage of inland waterway transport was created. This step of research includes a description of those factors.

The second step (Chapter 4) presents the DEMATEL (DEcision MAking Trial and Evaluation Laboratory) method, which has been used to analyse the correlations between factors.

Next, in the third step (chapter 5), the individual steps of the analysis, including the method to determine the degree of influence of individual factors, were presented. This step also includes the results obtained with the DEMATEL method.

The last and fourth step (chapter 6) presents conclusions based on the analysis results and further research directions.

3 SELECTED FACTORS INFLUENCING THE USAGE OF INLAND WATERWAY TRANSPORT

The selection of factors that were analyzed in the next steps was based on unstructured face-to-face interviews with two experts in the field of inland waterway transport in Poland. The conversations did not include any specific list of factors to be selected. They were in the form of brainstorming based on the respondent's knowledge and experience. The short interviews lasted approximately 30 minutes each.

The starting point for considering the factors that influence the use of inland navigation was the division of these factors into groups. These were infrastructure, fleet, people, and environment. During the process, about thirty factors were mentioned. The author aimed to narrow down the number of factors to five - eight, because carrying out the DEMETEL method analysis on more factors could reduce the number of respondents, based on those answers, the degree of influence was determined in subsequent steps.

Ultimately, the experts agreed on a list of seven factors that influence the use of inland waterways transport, which were subject to further analysis. These factors were: (1) accessibility and condition of ports, transshipment infrastructure, shipyards and service areas, (2) operating parameters of the linear infrastructure (waterways and locks), (3) technical condition of the fleet, (4) human errors committed by crew, infrastructure operators, and/or decision makers, (5) climate and weather conditions (floods, droughts, wind, ice, groundwater level), (6) financing the water transport system - repairs, ongoing maintenance of infrastructure; subsidies and discounts for ship owners, (7) availability of information (e.g. navigation messages), method of data collection and distribution, communication, and promotion of inland navigation.

In the next part of the study, especially in the tables, abbreviated names will be used. They are given next to the descriptions of the given factors.

1. Accessibility and condition of ports, transshipment infrastructure, shipyards, and service areas (Infrastructure). This factor takes into account the infrastructure that helps the fleet to be served and facilitate loading processes. It influences the usage of inland waterway transport because the fleet needs to be repaired (regularly and in case of adverse events) and to have ongoing service and operation possible. Also, rarely the door-to-door process can be performed using Inland Waterway Transportation, and the ability to load and unload is crucial and strongly affects the costs of the transportation process.
   This has been combined into one factor because both the port and the service infrastructure are used to serve the fleet.
2. Operating parameters of the linear infrastructure (waterways and locks) (Waterways). This factor takes into account the infrastructure connected to the waterways itself. It influences the use of inland waterway transport because these parameters determine the size of ships able to sail through it. And what is more important in Polish conditions is that it also includes the waterway depth, which influences the ship's draught, and results from the condition of the waterway, but also from weather conditions and water resources management.
3. Technical condition of the fleet (Ships). This factor takes into account ships, their presence, loading, and geometrical parameters, and their technical conditions. It influences the usage of inland waterway transport because ships determine the possibility, loading amount, and cargo type of transported goods. They also determine the parameters of the transport process.
4. Human errors committed by the crew, infrastructure operators, and/or decision makers (Errors). This factor takes into account all human errors that can occur in the transportation process and other actions that affect the transportation on inland waterways. It influences the usage of inland waterway transport because crew errors can lead to accidents and therefore ship, cargo, and infrastructure (e.g. lock gate) damage. The infrastructure (mostly locks) operators' errors can prolong the transportation process and can influence the condition of the infrastructure (negligence, errors in maintenance). Decision-maker errors can influence the use of inland waterway transport at each stage (legislation, waterway parameters, allocation of funding, etc.).
   All human errors have been grouped into one factor due to the willingness to reduce the number of factors and due to their similar nature.
5. Climate and weather conditions (floods, droughts, wind, ice, groundwater level) (Climate). This factor takes into account all the changes in water level and closure of the shipping route, which are related to the temporary and long-term weather phenomena. It influences the usage of inland waterway transport because it influences the parameters of the waterways and is independent of human actions.
6. Financing the water transport system - repairs, ongoing maintenance of infrastructure; subsidies and discounts for shipowners (Financing). This factor takes into account actions dependent on money. It influences the usage of inland waterway transport because it affects the parameters of waterways, technical conditions, and the age of locks. Financing in the form of subsidies can also influence the age and technical parameters of the fleet. And both can influence the interest in this branch of transport.
7. Availability of information (e.g. navigation messages), method of data collection and distribution, communication and promotion of inland navigation (Information). This factor takes into account information, data, communication, and promotion. Influences the use of inland waterway transport because easy access to navigation messages can have an impact on navigation safety. Data collection and distribution, for example, in the case of waterways depth may influence the ease of its forecasting and therefore readiness of its usage. Communication and promotion of inland navigation may influence knowledge of the society about this branch of transport, interest in transport, and the attractiveness of professions related to inland navigation.

4 THE DEMATEL METHOD

The DEcision MAking Trial and Evaluation Laboratory was originally developed for the needs of the Science and Human Affairs Programme, implemented in the years 1971–1976. The main objective of the project was to define cause-and-effect relationships between global and regional economic, social, and economic problems. This method was intended to help identify factors that directly or indirectly cause other problems to occur. [17]

In the 1990s [18] described this method as one of the most promising multi-attribute decision analysis expert tools for structuring complex decision-making issues and facilitating their resolution. In the 2000s, appearing publications began to confirm the use of DEMATEL in areas differed from the previous ones [e.g.19, 20, 21 and 22]. New applications contributed to changes, extensions, and improvements of the method. The advantages of the method, including, in particular, the ability to take into account the impact of hardness and couplings in interactions between elements and flexibility, make it useful to improve commonly known tools used in various fields.

In the basic version of the method, a multilevel scale is used to express the direct impact in relation to a pair of elements [17, 23 and 24]. It consists of a zero level (corresponding to the lack of direct impact of the first factor on the second) and a number of levels expressing a gradual increase in intensity up to the maximum impact (the author of this publication used a scale from 0 to 3 degrees expressing the influence of the first factor on the second as: 1 - small, 2 - medium, 3 - large).

On the basis of the adopted scale, the intensity of the direct impact of the i-th element on the j-th element is determined, marked with the symbol x^*_{ij}, where: i, j = 1, 2…n, where n is the number of system elements (in the case of this publication, the number n corresponds to the number of examined factors, i.e. n=7).

The direct impact matrix X* is used to show the direct impact structure.

$$X^* = \begin{bmatrix} 0 & x^*_{12} & x^*_{13} & \dots & x^*_{1n} \\ x^*_{21} & 0 & x^*_{23} & \dots & x^*_{2n} \\ x^*_{31} & x^*_{32} & 0 & \dots & x^*_{3n} \\ \vdots & \vdots & \vdots & \ddots & x^*_{n-1n} \\ x^*_{n1} & x^*_{n2} & x^*_{n3} & \dots & 0 \end{bmatrix}$$

To determine the structure of the total impact, an appropriately transformed standardised matrix of direct impact X is used. For its determination, the maximum sum of rows of elements of the X* matrix is used.

$$X = \frac{1}{\max\left\{\sum_{j=1}^{n} x^*_{ij}\right\}} \cdot X^*$$

The total impact structure is described by the total impact matrix $T=X+\Delta X$, where: ΔX is the indirect impact matrix. $\Delta X=X^2(I-X)^{-1}$, $T=X(I-X)^{-1}$ and I is a unit matrix consistent with X.

The role of individual elements of the system can be deduced on the basis of two indicators: s+ and s- obtained on the basis of row and column sums of the matrix T. The s+ indicator is the overall influence and expresses the relative importance of elements. While s- is a net influence and determines the causal (s– >0) or the effect (s– <0) nature of the elements.

The DEMATEL method allows taking into account the opinions of a group of independently working experts. This is achieved by aggregating the direct impact matrix, defined by individual K experts (in the case of this publication, the number of experts was K=10), and calculating the arithmetic average intensity of the direct impact, provided by experts. [17]

In recent years, there have been many publications related to transport in which the DEMATEL method is used.

An example can be given by [25] where the authors indicate a solution to increase the use of rail transport in the supply chain. This can be achieved through better coordination between those involved in the planning and implementation of freight transport services (rail and non-rail). It is therefore necessary to assess the interests of each of them and their mutual correlations.

The subject of sustainable mobility can also be considered using this method. [26] in his publication indicates the classification of groups of measures, dimensions and criteria that decision makers and planners should include in modified plans for the sustainable development of transport systems in order to support the development of sustainable transport.

Topics similar to those presented in this article appeared in [27]. The results show that management issues, policy bias, high entry cost requirements and lack of interconnections between rivers are the most important factors holding back the development of inland navigation in India. However, the [27] authors refer to the situation in India and the emphasis in the selection of factors was placed on technical and organisational issues (10 factors in total vs. 3 of 7 in this publication).

5 RESULTS OF THE DEMATEL METHOD ANALYSIS

To complement the direct impact matrix X*, the intensity of impact influence in relation to a pair of factors influencing the usage of inland waterway transport was determined by experts in this field. Experts represented the scientific community, representatives of the administration, and users of the inland waterways of Poland. Of the 15 invitations sent, the author received 10 responses and based on these responses, further steps were carried out.

Experts were asked to complete the matrix by participating in an online survey. The questionnaire contained questions that determined the degree of influence of individual factors (described in Chapter 3) on each other (, preserving the determination of the influence of factor i on j and j on i, because these values are not the same in most cases. From the 10 collected answers (as mentioned in Chapter 4) the arithmetic average was taken in each field of the X* matrix and its value rounded to the integer value was introduced. The matrix built on the basis of the experts' answers is presented in Table 1.

Table 1. The direct impact matrix for selected factors that influence the usage of inland waterway transport. Source: own work

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Infrastructure	0	1	2	1	0	2	2
(2) Waterways	3	0	2	2	0	2	1
(3) Ships	1	1	0	2	0	1	1
(4) Errors	2	2	2	0	0	2	1
(5) Climate	2	3	1	1	0	2	0
(6) Financing	3	3	2	1	0	0	2
(7) Information	2	1	1	2	0	2	0

Based on matrix X*, knowing that the maximum sum of rows of elements is 11 (for (6) Financing), standardised matrix of direct impact X was calculated. It can be seen in Table 2.

Table 2. The standardized direct impact matrix for selected factors that influence the use of inland waterways transport. Source: own work

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Infrastructure	0.000	0.091	0.182	0.091	0.000	0.182	0.182
(2) Waterways	0.273	0.000	0.182	0.182	0.000	0.182	0.091
(3) Ships	0.091	0.091	0.000	0.182	0.000	0.091	0.091
(4) Errors	0.182	0.182	0.182	0.000	0.000	0.182	0.091
(5) Climate	0.182	0.273	0.091	0.091	0.000	0.182	0.000
(6) Financing	0.273	0.273	0.182	0.091	0.000	0.000	0.182
(7) Information	0.182	0.091	0.091	0.182	0.000	0.182	0.000

Furthermore, the total impact matrix T is shown in Table 3.

Table 3. The total impact matrix for selected factors influencing the use of inland waterway transport. Source: own work

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Sum
(1)	0.559	0.511	0.632	0.506	0.000	0.625	0.547	3.380
(2)	0.906	0.522	0.747	0.664	0.000	0.733	0.565	4.138
(3)	0.522	0.420	0.377	0.486	0.000	0.455	0.385	2.645
(4)	0.787	0.637	0.698	0.472	0.000	0.685	0.523	3.801
(5)	0.826	0.747	0.652	0.569	0.000	0.714	0.459	3.967
(6)	0.972	0.785	0.795	0.647	0.000	0.632	0.676	4.508
(7)	0.733	0.528	0.580	0.582	0.000	0.643	0.404	3.469
Sum:	5.306	4.151	4.481	3.925	0.000	4.487	3.558	

Finally, the results of the DEMATEL method, in a form of values of significance indicator and relation indicator, are presented in Table 4.

Table 4. The values of the significance indicator and the relation indicator for selected factors that influence the use of inland waterway transport. Source: own work

	significance indicator s^+	relation indicator s^-	cause or effect
(1) Infrastructure	8.686	-1.925	Effect
(2) Waterways	8.289	-0.013	Effect
(3) Ships	7.127	-1.836	Effect
(4) Errors	7.726	-0.124	Effect
(5) Climate	3.967	3.967	Cause
(6) Financing	8.995	0.020	Cause
(7) Information	7.028	-0.089	Effect

The results presented in Table 4 indicate that the most important factor among the factors analyzed is financing the water transport system, repairs, ongoing maintenance of the infrastructure; subsidies and discounts for shipowners (s^+=8.995). However, accessibility and condition of ports, transshipment infrastructure, shipyards and service areas (s^+=8.686) as well as operational parameters of linear infrastructure (waterways and locks) (s^+=8.289) also received high significance indicators.

Of the seven investigated factors, as a result of the DEMATEL analysis, 2 were recognized as causes (Financing the water transport system - repairs, ongoing maintenance of infrastructure; subsidies and discounts for shipowners (s^-=0.020) and Climate and weather conditions (floods, droughts, wind, ice, groundwater level (s^-=3.967)), and the remaining 5 as effects, but nevertheless the values of two of them (Operating parameters of the linear infrastructure (waterways and locks) (s^-=-0.013) and Availability of information (e.g. navigation messages), method of data collection and distribution, communication and promotion of inland navigation (s^-=-0.089)), despite being negative, were close to zero, which suggests that they can be considered as both cause and effect.

6 CONCLUSIONS

The results of the DEMATEL analysis are subject to expert responses. Therefore, it is important that the questions are unambiguous and that the purpose of the study is understood. Since the questionnaires were sent by name, experts had the opportunity to refer to the content of the questions and give their opinion on the study.

There were voices among the respondents that the purpose of the study was not clear to everyone, making it difficult for them to determine the relationship between the factors, according to them, weakly dependent, because they considered these questions meaningless.

This is because the introduction that the experts saw before taking the survey was short to avoid discouraging the respondents with too much time necessary to devote to completing the survey.

The experts also pointed out the wide range of individual factors that limited the precision of the answers. This was due to the fact that the author wanted to limit the size of the matrix (the number of factors studied) without omitting the most important factors.

These are the weaknesses of this survey, which in the future can be overcome by preparing the survey in a more detailed form, which will reduce the number of respondents but increase the quality of responses.

Regardless of these disadvantages, the results of the analysis indicate that financing and infrastructure condition (both waterways and ports) are the most important factors among those analyzed. They are the most significant indicators. This leads to the conclusion that if one is looking for a way to increase freight transport on inland waterways, then one should focus on these areas.

Financing the water transport system - repairs, ongoing maintenance of infrastructure; subsidies and discounts for shipowners; Accessibility and condition of ports, transshipment infrastructure, shipyards, and service areas and Operating parameters of the linear infrastructure (waterways and locks) are of the most significance of analyzed factors.

The division into causes and effects of the examined factors influencing the usage of inland waterway transport shows that the Climate and weather conditions (floods, droughts, wind, ice, groundwater level is strongly rated as a cause of other factors. But it is also the one that people's influence is very limited. The second cause is Financing the water transport system, repairs, ongoing maintenance of infrastructure; subsidies and discounts for shipowners, but its score is very low. Similarly to score of Operating parameters of the linear infrastructure (waterways and locks) and Availability of information (e.g. navigation messages), method of data collection and distribution, communication and promotion of inland navigation being effects in this classification. It means that information and waterways parameters are both causes and effects, so can influence other factors, but also can be influenced.

As a next research step, the Author plans to improve the survey. The number of factors could be greater, which would allow to tighten its range. E.g. *Financing the water transport system - repairs, ongoing maintenance of infrastructure; subsidies and discounts for shipowners (Financing)* could be divided into *Financing repairs, ongoing maintenance of infrastructure,* and *Subsidies and discounts for shipowners*. And the factor of *Financing infrastructure investments* could be added. Then the survey may be used for Path Analysis and estimating weights of examined factors. The result of such research may be more accurate recommendations on improving transportation on inland waterways.

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