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Use of the grey incidence analysis in the inland waterway transport system assessment

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Abstract

Inland waterway transport (IWT) is currently in focus for EU countries due to a shift in policy towards a more sustainable and green economy. The aim of this article is to analyze the possibility of using a grey incidence analysis (GIA) to identify key factors related to the functioning of the IWT system. GIA is classified as a multi-criteria decision-making method and is one of the key applications of grey systems theory (GTS), i.e., systems with incomplete and uncertain information about structure and behavior. GIA identifies the most favorable (or quasi-preferred) system characteristics and the most favorable (or quasi-preferred) system factors. The identification of such characteristics and factors enables a reduction in the inconsistencies in decision making on the functioning of the system. The application of the GIA to the assessment of the IWT system is an original concept.

Introduction

Inland waterway transport (IWT) is an important sector of the economic activity of the European Union (EU) and its importance is increasing as countries move towards more sustainable and green economies. IWT is characterized by many features which, in the situation of well-developed waterways, make it possible to effectively compete with land transport, not just in terms of operating costs.

Low energy consumption in relation to the transport work performed, high load capacity of vessels and their versatility, high durability of infrastructure facilities and vessels as well as a relatively low nuisance for people and the environment are important, positive features of inland water transport compared to other modes of transport. It has long been the goal of EU countries to shift goods transport from roads to greener means. Inland navigation is able to safely and reliably transport cargo (and passengers) in rivers, canals, lakes, and other waterways, including inside ports. Every year in the EU, transport performance of 150 billion ton-kilometers is performed on inland waterways. EUR 2.2 billion of added value in the IWT sector generates direct and indirect economic added value of EUR 13.2 billion. In addition, each of the five largest seaports in the EU is connected to inland waterways. The TEN-T corridor network (trans-European transport networks) includes 230 inland ports. About 75 of these ports are part of the core network and a further 40 of them are both inland and seaports. From the port of Rotterdam, about 1/3 of all goods are cleared by inland waterways (COM, 2006).

The European Green Deal has set the ambitious goal for EU economies to shift a significant proportion of freight from road to rail and inland waterways. Although inland water transport currently accounts for only about 6.5% of freight transport, the direction of changes has already been indicated. The EU policy promotes solutions related to intermodality and the reduction of emissions and energy consumption of the transport system at the continental level (EC, 2011).

This requires increasing IWT capacity and improving their management from 2021 (COM, 2013). Therefore, transport and water management policies and measures must focus on adapting the technological and organizational aspects of inland navigation to the new guidelines and the new market demand structure. The subject of the article, which is to analyze the possibility of using grey incidence analysis (GIA) to identify key factors related to the functioning of the IWT system, fits perfectly into these activities.

Assessment of the inland waterway transport system functioning

On this subject in the literature, there are numerous studies on the functioning of inland water transport. The studies emphasize its properties and specificity and indicate the existing potential, measurable benefits, and possibilities of use (Kulczyk & Winter, 2003; Rolbiecki, Rydzykowski & Wojewódzka-Król, 2007; Hekkenberg & Thill, 2014; Wojewódzka-Król, 2015; Li, Notteboom & Wang, 2016; Woś & Han, 2017).

A lot of space has been devoted to the search for optimal solutions in the functioning of this type of transport (Fischetti & Toth, 1992; Charlier & Ridolfi, 1994; Zhang, Janic & Tavasszy, 2015). Organizational and legal issues are considered separately (Molnar, 2001; Semenov, 2006), as well as economic (Rozwój, 2016; Gus-Puszczewicz, 2018), technical, and technological issues (Tołkacz, 2010, 2011; Woś & Han, 2017) or ensuring safety during loading and unloading operations in harbor (Fraitag et al., 2022).

Some publications analyze issues that combine several different aspects (Semenov, 2005; Montwiłł, 2014; Wojewódzka-Król & Rolbiecki, 2014; Marin & Olaru, 2015; Wojewódzka-Król, 2015), or analyze one existing or prospective case (Petnga & Austin, 2016; Woś & Han, 2017). Decision-making problems relate to the shaping of transport networks and adapting individual infrastructure elements to the existing demand, distribution of traffic in the network, minimizing the time and costs of implementing individual stages of transport processes, or the selection of solutions shaping a new dimension of transport infrastructure (Hrušovský et al., 2018; Tzannatos, Tselentis & Corres, 2016; Wang et al., 2019).

Operational research, linear programming, and game theory are used to analyze systemic transport problems (Nelson et al., 2017; Tanaka & Okada, 2019; Munuzuri et al., 2020). Some of the problems are formulated as a single-criteria optimization task and then the objective function is to minimize the time of the process, minimize costs, or maximize profits (Wiegmans & Konings, 2015; Hofbauer & Putz, 2020). In this case, the constructed models are considered separately, which, however, does not lead to general formulations (Jacyna, 2001, 2009; Smoliński, 2014).

Transport problems are increasingly more often solved when using a multi-criteria approach, in which the problem of minimizing the target function is described, and where the partial criteria are, for example, transport cost, safety, service time, or the amount of cargo transported (Fischetti & Toth, 1992; Geneletti, 2005; Jacyna, 2009; Al Enezy et al., 2017; Hossain et al., 2020).

The assessment of the systems is made not only from the point-of-view of efficiency, but also safety, so that it is possible to identify more advantageous solutions that meet, above all, the expectations of potential users (Żak, Jacyna-Gołda & Wasiak, 2014; Melo et al., 2017; Załoga, 2017; Dvorak et al., 2020). The use of a multi-criteria approach requires the use of multi-criteria decision support tools. These tools have been increasingly represented in recent years (Jacyna, 2001, 2009; Geneletti, 2005; Fazi, Fransoo & Van Woensel, 2015).

Characteristics of the Grey Incidence Analysis

Grey incidence analysis (GIA) is one of the most important decision-making methods in grey systems theory (GTS). Grey systems are systems with incomplete and uncertain information about structure and behavior (Deng, 1989). GTS does not require many assumptions about the size and distribution of the sample that is accepted for research – the minimum number of data must not be less than four. Therefore, it has an advantage over statistical methods, or fuzzy or coarse sets (Liu, Forrest & Yang, 2012; Rajesh & Ravi, 2015).

Using the theory of grey systems, it is possible to forecast the future behavior of the system, assess the interdependence of observation vectors, evaluate the effectiveness of the system's reaction to possible situations, and make optimal decisions as well as group and study clusters. The basic assumption of the GIA is that the closeness of a relationship can be judged on the level of similarity in the geometric patterns of the sequence curves. The more similar the curves are, the higher the degree of similarity between the sequences exists, and vice versa (Liu & Lin, 2010).

The measure of the similarity of vectors is the so-called relative degree of incidence (similarity) between the observation vectors X_i and Y_j, where Y represents the system responses and X the system influencing factor. The relative degree of incidence (similarity) between the observation vectors X_i and Y_j has properties that are very important for system evaluation (Liu & Lin, 2010):

(a) $0 < R_{ij} \leq 1$;
(b) R_{ij} is related only to the geometrical shape of the vectors X_i and Y_j, but not to their spatial arrangement;
(c) every two vectors are always at least minimally related, so R_{ij} is not zero;
(d) the more the observation vectors are related (similar), the higher the value of R_{ij};
(e) if the observation vectors are parallel or fluctuate around one another, the value of R_{ij} is equal to or close to 1;
(f) if one of the vectors changes, R_{ij} also changes;
(g) if the length of the vectors changes, so does R_{ij};
(h) identity relationship ($R_{ii} = R_{jj} = 1$) and the symmetry relation ($R_{ij} = R_{ji}$) are used.

The relative degree of incidence enables a good assessment of the similarity of the behavior of the vector pair, as well as the degree of their relationship. This enables the most favorable system characteristics and factors to be identified according to the guidelines below (Liu & Lin, 2010):

- If there are k and $i \in \{1, 2, ..., s\}$ satisfying $R_{kj} \geq R_{ij}$, for $j = 1, 2, ... m$, then the system characteristic Y_k is more favorable than Y_i, denoted as $Y_k > Y_i$. If for any $i = 1, 2, ..., s$, there is always $Y_k > Y_i$, then Y_k is the most favorable feature of the system. This means that Y_k is the most advantageous sequence to describe the system characteristics.
- If there are l and $j \in \{1, 2, ... m\}$ satisfying $R_{il} \geq R_{ij}$, for $i = 1, 2, ... s$, then the corresponding factor X_l is more favorable than X_j, written as $X_l > X_j$. If for any $l = 1, 2, ... s$, there is always $X_l > X_j$, then X_l is the most favorable system factor. This means that X_l is the most favorable system factor that will influence the future development of this system.

There may not be the most favorable system characteristic and factor in a system. However, there are always quasi-preferred system characteristics and factors that can be identified according to the following guidelines (Liu & Lin, 2010):

- If there are k and $i = 1, 2, ... s$ satisfying $\Sigma^m_{j=1} R_{kj} \geq \Sigma^m_{j=1} R_{ij}$ then the characteristics of the Y_k system are more quasi-favorable than Y_i, which means $Y_k \geq Y_i$. If for any $i = 1, 2, ... s$, there is always $Y_k \geq Y_i$, then Y_k is the quasi-preferred characteristic of the system. This means that Y_k is more appropriate to describe the system characteristics compared to other characteristics.
- If there are l and $j \in \{1, 2, ... m\}$, satisfying $\Sigma^s_{i=1} R_{il} \geq \Sigma^s_{i=1} R_{ij}$ the corresponding factor X_l is more favorable than X_j, which is $X_l \geq X_j$. If for any $l = 1, 2, ... s$ there is always $X_l \geq X_j$, X_l is the quasi-preferred system factor. This means that X_l is a more appropriate system factor to influence the future development of that system as compared to the other factors.

Therefore, the method is widely used in the analysis of various systems (Cui, Zhou & Liu, 2009; Goyal & Grover, 2012; Karimi & Forrest, 2014; Tan et al., 2014; Guo & Zhang, 2015; Wang, Liu & Bi, 2015; Liu et al., 2016; Xie, Hu & Yin, 2016; Zhu et al., 2016; Tabor, 2018, 2021).

Methodology

Based on the literature, three main indicators of the effects of the inland water transport system have been established, which have been adopted as the system characteristics: Y_1 – production value (million euro), Y_2 – value added at factor cost (million euro), and Y_3 – turnover or gross premiums written (million euro). At the same time, the following indicators were adopted as systemic factors: X_1 – navigable inland waterways – all waterways type (kilometer), X_2 – inland freight water transport enterprises (number), X_3 – persons employed (number), X_4 – self-propelled barge (number), X_5 – self-propelled barge (thousand tones), X_6 – dumb and pushed vessel (number), X_7 – dumb and pushed vessel (thousand tones), X_8 – power of self-propelled vessels by load capacity (megawatt), X_9 – total transported goods (thousand tones), and X_{10} – investment (million euro). The EUROSTAT database was used as the data source; data related to 2019.

To identify the most important characteristics of the inland water transport system and system factors, the GIA procedure algorithm was used, including the following activities (Liu et al., 2016):

1) Building a sequence of system characteristics and the sequence of system factors. If Y_1, Y_2, ..., Y_s is a series of system characteristics, and X_1, X_2, ..., X_m is a series of system factors, n is the number of observation values for $y_i(k)$ and $x_j(k)$ where (k = 1, 2, ..., n; j = 1, 2, ..., m), then the sequences of the system characteristic Y_i and the sequences of the system factor X_j can be expressed by the following formulas:

$$Y_i = (y_i(1), y_i(2), \dots, y_i(k), \dots, y_i(n)),\ i = 1,2, \dots, s$$

$$X_j = (x_j(1), x_j(2), \dots, x_j(k), \dots, x_j(n)),\ j = 1,2, \dots, m$$

2) Calculation of the initial image of Y_i and X_j. The initial images of Y_i and X_i are calculated using equations that transform the values of the observations into dimensionless values, so that:

$$Y_i' = \frac{Y_i}{y_i(1)} = (y_i'(1), y_i'(2), \dots, y_i'(k), \dots, y_i'(n))$$
$$i = 1,2,\dots,s$$
$$X_j' = \frac{X_j}{x_j(1)} = (x_j'(1), x_j'(2), \dots, x_j'(k), \dots, x_j'(n))$$
$$j = 1,2,\dots,m \qquad (1)$$

where:

$$y_i'(k) = \frac{y_i(k)}{y_i(1)},\quad k = 1,2,\dots,n$$
$$x_j'(k) = \frac{x_j(k)}{x_j(1)},\quad k = 1,2,\dots,n$$

3) Compute the images of the zero starting points of Y'_i and X'_j. Images of the zero starting points of Y'_i and X'_j are presented by the following equations:

$$Y_i'^0 = (y_i'^0(1), y_i'^0(2), \dots, y_i'^0(k), \dots, y_i'^0(n))$$
$$i = 1,2,\dots,s$$
$$X_j'^0 = (x_j'^0(1), x_j'^0(2), \dots, x_j'^0(k), \dots, x_j'^0(n))$$
$$j = 1,2,\dots,m \qquad (2)$$

where:

$$y_i'^0(k) = y_i'(k) - y_i'(1),\quad k = 1,2,\dots,n$$
$$x_j'^0(k) = x_j'(k) - x_j'(1),\quad k = 1,2,\dots,n$$

4) Calculation of [s_i] and [s_j] using the following equations:

$$|s_i'| = \left| \sum_{k=2}^{n-1} y_i'^0(k) + \frac{1}{2} y_i'^0(n) \right|,\quad i = 1,2,\dots,s$$
$$|s_j'| = \left| \sum_{k=2}^{n-1} x_j'^0(k) + \frac{1}{2} x_j'^0(n) \right|,\quad j = 1,2,\dots,m$$
$$|s_j' - s_i'| = \left| \sum_{k=2}^{n-1} \left(x_j'^0(k) - y_i'^0(k)\right) + \frac{1}{2}\left(x_j'^0(n) - y_i'^0(n)\right) \right|$$
$$i = 1,2,\dots s;\quad j = 1,2,\dots,m;\quad k = 1,2,\dots,n \qquad (3)$$

5) Compute the relative degree of grey similarity r_{ij} and obtain the relative grey similar matrix **R**. The relative degree of grey similarity r_{ij} is expressed by the following expression:

$$r_{ij} = \frac{1 + |s_i'| + |s_j'|}{1 + |s_i'| + |s_j'| + |s_j' - s_i'|}$$
$$i = 1,2,\dots,s;\quad j = 1,2,\dots,m \qquad (4)$$

So, we can obtain the relative grey similarity matrix **R**. The entries in the i-th row (i = 1, 2, ..., s) and in the j-th column (j = 1, 2, ..., m) are the relative degrees of the grey sequence similarity of the Y_i characterization and the factor X_j sequence for the system:

$$\mathbf{R} = [r_{ij}]_{s\times m} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & & \vdots \\ r_{s1} & r_{s2} & \cdots & r_{sm} \end{bmatrix}_{s\times m}$$

6) Analyze the relative grey similarity matrix **R** and identify the most favorable (or quasi-preferred) system features and system factors.

Findings

The structure of the sequence of IWT system characteristics and factors was based on EUROSTAT indicators from only 9 countries: Bulgaria, Croatia, Czechia, Finland, France, Germany, Poland, Romania, and Slovakia (Table 1). In the case of other countries, the databases were incomplete (the data has not been made available).

Using the data from Table 1, the initial images of the sequence of Y characteristics and the sequence of X factors were calculated according to the formula (1). Table 2 presents the results of these calculations.

Using formula (2), and values taken from Table 2, the zero images of the initial points of the sequence of Y characteristics and the sequence of X factors were calculated. The obtained results are summarized in Table 3.

Table 1. Observation values of IWT characteristic and IWT factors (EUROSTAT, 2022)

	IWT Characteristics Y			IWT Factors X									
	y_1	y_2	y_3	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
BG	29.4	7.4	28.6	470	25	534	34	52.5	106	179.6	28.8	18,449	161.8
HR	2.5	–0.1	2.5	1016.9	5	45	15	16	98	75	10	6491	31.1
CZ	28.8	5.0	29.4	720	25	287	33	33	95	50	15	779	81.1
FI	6.3	2.0	8.0	8125	10	51	189	16	55	8	40	527	133.6
FR	400	161.4	397.3	4827	660	1941	700	639	342	453	307	64,207	5229.4
DE	1036.7	530.2	1715.4	7675	549	4981	1171	1805	805	740	892	205,066	11,272.2
PL	44.4	9.1	45.5	3722.2	261	593	80	62	402	183	30	2870	235.9
RO	121.4	38.2	114.9	2635	72	1574	123	160	1021	1448	83	33,261	1345.5
SK	37.3	9.1	74.7	172	19	301	9	10.6	99	159.6	4.2	6430	3382.7

BG – Bulgaria, HR – Croatia, CZ – Czechia, FI – Finland, FR – France, DE – Germany, PL – Poland, RO – Romania, SK – Slovakia. Y_1 – production value (million euro), Y_2 – value added at factor cost (million euro), Y_3 – turnover or gross premiums written (million euro), X_1 – navigable inland waterways – all waterways type (kilometer), X_2 – inland freight water transport enterprises (number), X_3 – persons employed (number), X_4 – self-propelled barge (number), X_5 – self-propelled barge (thousand tones), X_6 – dumb and pushed vessel (number), X_7 – dumb and pushed vessel (thousand tones), X_8 – power of self-propelled vessels by load capacity (megawatt), X_9 – total transported goods (thousand tones), and X_{10} – investment (million euro).

Table 2. Initial images of Y_i and X_j

	$y_1(k)$	$y_2(k)$	$y_3(k)$	$x_1(k)$	$x_2(k)$	$x_3(k)$	$x_4(k)$	$x_5(k)$	$x_6(k)$	$x_7(k)$	$x_8(k)$	$x_9(k)$	$x_{10}(k)$
BG	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HR	0.09	–0.01	0.09	2.16	0.20	0.08	0.44	0.30	0.92	0.42	0.35	0.35	0.19
CZ	0.98	0.68	1.03	1.53	1.00	0.54	0.97	0.63	0.90	0.28	0.52	0.04	0.50
FI	0.21	0.27	0.28	17.29	0.40	0.10	5.56	0.30	0.52	0.04	1.39	0.03	0.83
FR	13.61	21.81	13.89	10.27	26.40	3.63	20.59	12.17	3.23	2.52	10.66	3.48	32.32
DE	35.26	71.65	59.98	16.33	21.96	9.33	34.44	34.38	7.59	4.12	30.97	11.12	69.67
PL	1.51	1.23	1.59	7.92	10.44	1.11	2.35	1.18	3.79	1.02	1.04	0.16	1.46
RO	4.13	5.16	4.02	5.61	2.88	2.95	3.62	3.05	9.63	8.06	2.88	1.80	8.32
SK	1.27	1.23	2.61	0.37	0.76	0.56	0.26	0.20	0.93	0.89	0.15	0.35	20.91

Table 3. Images of zero starting points of initial images Y'_i and X'_j

	$y'^0_1(k)$	$y'^0_2(k)$	$y'^0_3(k)$	$x'^0_1(k)$	$x'^0_2(k)$	$x'^0_3(k)$	$x'^0_4(k)$	$x'^0_5(k)$	$x'^0_6(k)$	$x'^0_7(k)$	$x'^0_8(k)$	$x'^0_9(k)$	$x'^0_{10}(k)$
BG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HR	–0.91	–1.01	–0.91	1.16	–0.80	–0.92	–0.56	–0.70	–0.08	–0.58	–0.65	–0.65	–0.81
CZ	–0.02	–0.32	0.03	0.53	0.00	–0.46	–0.03	–0.37	–0.10	–0.72	–0.48	–0.96	–0.50
FI	–0.79	–0.73	–0.72	16.29	–0.60	–0.90	4.56	–0.70	–0.48	–0.96	0.39	–0.97	–0.17
FR	12.61	20.81	12.89	9.27	25.40	2.63	19.59	11.17	2.23	1.52	9.66	2.48	31.32
DE	34.26	70.65	58.98	15.33	20.96	8.33	33.44	33.38	6.59	3.12	29.97	10.12	68.67
PL	0.51	0.23	0.59	6.92	9.44	0.11	1.35	0.18	2.79	0.02	0.04	–0.84	0.46
RO	3.13	4.16	3.02	4.61	1.88	1.95	2.62	2.05	8.63	7.06	1.88	0.80	7.32
SK	0.27	0.23	1.61	–0.63	–0.24	–0.44	–0.74	–0.80	–0.07	–0.11	–0.85	–0.65	19.91

Then, using formulas (3), the S components were calculated (Table 4). The S components are necessary to compute the relative grey degrees of similarity with R, these are: $S_{i=1} = 48.92$, $S_{i=2} = 93.90$, $S_{i=3} = 74.68$.

The next step was to calculate the relative degrees of grey similarity and present them in the form of the **R** matrix. The formula (4) was used for the calculations, to find that (5).

$$\mathbf{R} = \left[r_{ij}\right]_{3\times 10} = \begin{bmatrix} 0.9552 & 0.9362 & 0.6115 & 0.9044 & 0.9564 & 0.7028 & 0.6002 & 0.9136 & 0.6027 & 0.7117 \\ 0.7875 & 0.8001 & 0.5584 & 0.8236 & 0.7390 & 0.6062 & 0.5525 & 0.7165 & 0.5538 & 0.9044 \\ 0.8610 & 0.8768 & 0.5733 & 0.9063 & 0.8001 & 0.6333 & 0.5659 & 0.7719 & 0.5675 & 0.8220 \end{bmatrix} \quad (5)$$

Table 4. Values of the *S* components for the calculation of *R*

	$j = 1$	$j = 2$	$j = 3$	$j = 4$	$j = 5$	$j = 6$	$j = 7$	$j = 8$	$j = 9$	$j = 10$
$\lvert S'_j \rvert$	53.79	56.16	10.52	60.60	44.62	19.55	9.41	40.39	9.65	116.23
$\lvert S'_j - S'_{i=1} \rvert$	4.87	7.24	38.41	11.68	4.31	29.37	39.52	8.54	39.27	67.31
$\lvert S'_j - S'_{i=2} \rvert$	40.11	37.75	83.39	33.30	49.29	74.35	84.50	53.52	84.25	22.33
$\lvert S'_j - S'_{i=3} \rvert$	20.89	18.53	64.17	14.08	30.07	55.13	65.28	34.30	65.03	41.55

Finally, a matrix analysis was performed to identify the most favorable (or quasi-preferred) characteristics and the most favorable (or quasi-preferred) factors:

$$\sum_{j=1}^{10} r_{1j} = 7.8947 \geq \sum_{j=1}^{10} r_{3j} = 7.3782 \geq \sum_{j=1}^{10} r_{2j} = 7.0419$$

$$Y_1 \geq Y_3 \geq Y_2$$

The analysis of the results shows that the most favorable characteristic for the inland water transport system is *production value in million euro*. At the same time, the most favorable system factors are: *number of self-propelled barges* and *number of inland freight water transport enterprises* as well as *navigable inland waterways – all waterways type (in kilometer).* It is determined that:

$$\sum_{i=1}^{3} r_{i4} = 2.6344 \geq \sum_{i=1}^{3} r_{i2} = 2.6130 \geq \sum_{i=1}^{3} r_{i1} = 2.6038 \geq$$

$$\sum_{i=1}^{3} r_{i5} = 2.4955 \geq \sum_{i=1}^{3} r_{i10} = 2.4381 \geq \sum_{i=1}^{3} r_{i8} = 2.4020 \geq$$

$$\sum_{i=1}^{3} r_{i6} = 1.9424 \geq \sum_{i=1}^{3} r_{i3} = 1.7431 \geq \sum_{i=1}^{3} r_{i9} = 1.7239 \geq$$

$$\geq \sum_{i=1}^{3} r_{i7} = 1.7186$$

$$\sum_{i=1}^{3} r_{ij}, (j = 1,2,3)$$

$$X_4 \geq X_2 \geq X_1 \geq X_5 \geq X_{10} \geq X_8 \geq X_6 \geq X_3 \geq X_9 \geq X_7$$

Conclusion and discussion

Shipping companies has to be able to safely and reliably transport cargo, reduce traffic congestion, and provide lower energy consumption and improved environmental performance. According to EUROSTAT data in 2019, Finland (8125 *in kilometers*), Germany (7675), and the Netherlands (6297) had the longest waterways. On the other hand, most goods were transported by the Netherlands (357,069 *in thousand tons*), Germany (205,066), and Belgium (155,695).

At the same time, the length of the roads and the number of transported goods does not always translate directly into the production value. Moreover, in times of sustainable development and green economy, the value of production or other purely financial indicators should not be the only important measures – characteristics of the functioning of the system. The performance of a system is usually influenced by many factors, of a very different nature. Therefore, in order to reliably assess the functioning of the system in the modern economy, it is necessary to identify the characteristics and system factors describing the system from various points-of-view (technical, organizational, human, and environmental) and with the use of various measures (quantitative and qualitative).

This paper represents the original application of the GIA to identify key characteristics and the most favorable system factors in the assessment of an IWT system. It is true that the analysis used little differentiated characteristics and systemic factors, but it resulted from the access to such data. During the pandemic, conducting questionnaire surveys was unfortunately difficult. This is the main limitation of the research.

On the other hand, the choice of a method in the area of GTS is perfectly justified, because GIS enables the use of not only quantitative but also qualitative data, which may contribute to further research on this topic. The proposed approach has the following advantages: (a) it is relatively easy to apply, (b) it is beneficial in the situation of imprecise and incomplete information, and (c) it can be applied even in the case of a small sample. Using the proposed approach, the most favorable characteristic of the inland water transport system is the *production value in million euro* and the most favorable system factors are *number of self-propelled barges* and *number of inland freight water transport enterprises* as well as *navigable inland waterways – all waterways type in kilometer.*

The application of the GIA in the area of IWT is an original concept. The proposed approach could be an important tool for the assessment and improvement of the inland water transport system.

References

1. Al Enezy, O., Van Hassel, E., Sys, C. & Vanelslander, T. (2017) Developing a cost calculation model for inland navigation. *Research in Transportation Business & Management* 23, pp. 64–74.
2. Charlier, J. & Ridolfi, G. (1994) Intermodal transportation in Europe: of modes, corridors and nodes. *Maritime Policy and Management* 21(3), pp. 237–250.
3. COM (2006) *Communication from the Commission on the promotion of inland waterway transport "NAIADES" – an integrated European action programme for inland waterway transport, COM/2006/0006 final {SEC(2006) 34}*. Available from: eur-lex.europa.eu/ [Accessed: May 04, 2022].
4. COM (2013) *Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee of the regions, Towards quality inland waterway transport NAIADES II / COM/2013/0623 final*. Available from: eur-lex.europa.eu/ [Accessed: May 04, 2022].
5. Cui, J.F., Zhou, R.J. & Liu, R. (2009) Grey incidence analysis based on coefficient of determination and its economic application with the data of Central Henan Urban Agglomeration. *IEEE International Conference on Grey Systems and Intelligent Services*, pp. 32–36.
6. Deng, J.L. (1989) Introduction of grey system theory. *Journal of Grey Systems* 1, pp. 1–24.
7. Dvorak, Z., Rehak, D., David, A. & Cekerevac, Z. (2020) Qualitative approach to environmental risk assessment in transport. *International Journal of Environmental Research and Public Health* 17 (15), 5494.
8. EC (2011) *White Paper 2011. Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system*. European Commission, Brussels.
9. EUROSTAT (2022) *Inland waterways transport*. [Online]. Available from: http://ec.europa.eu/eurostat/web/transport/database [Accessed: April 27, 2022].
10. Fazi, S., Fransoo, J.C. & Van Woensel, T. (2015) A decision support system tool for the transportation by barge of import containers: a case study. *Decision Support System* 79, pp. 33–45.
11. Fischetti, M. & Toth, P. (1992) An additive bounding procedure for the asymmetric travelling salesman problem. *Mathematical programming* 53, pp. 173–197.
12. Fraitag, D.N., Popescu-Stelea, M., Moraru, R.I. & Băbuţ, G.B. (2022) Prevention activities in ship loading and uploading operations. *MATEC Web of Conferences* 354, 00003.
13. Geneletti, D. (2005) Multicriteria analysis to compare the impact of alternative road corridors: a case study in northern Italy. *Impact Assessment and Project Appraisal* 23(2), pp. 135–146.
14. Goyal, S. & Grover, S. (2012) Applying fuzzy grey relational analysis for ranking the advanced manufacturing systems. *Grey Systems: Theory and Application* 2(2), pp. 284–298.
15. Guo, K. & Zhang, Q. (2015) Detecting communities in social networks by local affinity propagation with grey relational analysis. *Grey Systems: Theory and Application* 5(1), pp. 31–40.
16. Gus-Puszczewicz, A. (2018) Inland waters in the development of inland shipping. Transportation – business operations and sustainable development. *Transport Economics and Logistics* 77, pp. 33–40.
17. Hekkenberg, R. & Thill, C. (2014) *Retrofit solutions for inland ships: The MoVe IT approach*. European Inland Waterway Navigation Conference, Budapest, Hungary.
18. Hofbauer, F. & Putz, L.M. (2020) External costs in inland waterway transport: an analysis of external cost categories and calculation methods. *Sustainability* 12, 5874.
19. Hossain, N.U.I., Amrani, S.E., Jaradat, R., Marufuzzaman, M., Buchanan, R., Rinaudo, C. & Hamilton, M. (2020) Modeling and assessing interdependencies between critical infrastructures using Bayesian network: a case study of inland waterway port and surrounding supply chain network. *Reliability Engineering & System Safety* 198, 106898.
20. Hrušovsky, M., Demir, E., Jammernegg, W. & Van Woensel, T. (2018) Hybrid simulation and optimization approach for green intermodal transportation problem with travel time uncertainty. *Flexible Services and Manufacturing Journal* 30, pp. 486–516.
21. Jacyna, M. (2001) *Modelowanie wielokryterialne w zastosowaniu do oceny systemów transportowych*. Prace Naukowe Politechniki Warszawskiej, Transport, z. 47, Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.
22. Jacyna, M. (2009) *Modelowanie i ocena systemów transportowych*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.
23. Karimi, T. & Forrest, J. (2014) Analyzing the results of buildings energy audit by using grey incidence analysis. *Grey Systems: Theory and Application* 4(3), pp. 386–399.
24. Kulczyk, J. & Winter, J. (2003) *Śródlądowy transport wodny*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.
25. Li, J.Y., Notteboom, T.E. & Wang, J.J. (2016) An institutional analysis of the evolution of inland waterway. *Geojournal* 82, pp. 867–886.
26. Liu, S.F. & Lin, Y. (2010) *Grey Systems: Theory and Applications*. Berlin: Springer-Verlag.
27. Liu, S., Forrest, J. & Yang, Y. (2012) A brief introduction to grey systems theory. *Grey System: Theory and Application* 2(2), pp. 89–104.
28. Liu, W., Zhang, J., Wu, C. & Chang, X. (2016) Identifying key industry factors of remanufacturing industry using grey incidence analysis: A case of Jiangsu province. *Grey Systems: Theory and Application* 6(3), pp. 398–414.
29. Marin, G. & Olaru, M. (2015) Modal strategic decisions in transport and their role in sustainable development: an example from Romania. *Procedia Economics and Finance* 32, pp. 657–664.
30. Melo, I.C., Alves Junior, P.N., Perico, A.E., Guzman, M.G.S. & Rebelatto, D.A.N. (2017) Benchmarking freight transportation corridors and routes with data envelopment analysis (DEA). *Benchmark: An International Journal* 25, pp. 713–742.
31. Montwiłł, A. (2014) Trends in the development of European inland freight transport. *Scientific Journals, Maritime University of Szczecin* 37(109), pp. 67–71.
32. Molnar, E. (2001) *Transport policies in the Central and Eastern Europe a decade of integration: results and new challenges*. Paris: Transport Policy Forum.
33. Munuzuri, J., Onieva, L., Cortes, P. & Guadix, J. (2020) Using IoT data and applications to improve port-based intermodal supply chains. *Computer & Industrial Engineering* 139, 105668.

34. Nelson, K.S., Camp, J.V., Philip, C.E. & Abkowitz, M.D. (2017) Agent-based model of navigable inland waterway tow operation procedures. *Transportation Research Record: Journal of the Transportation Research Board* 2611, pp. 11–18.
35. Petnga, L. & Austin, M. (2016) Model-based design and formal verification processes for automated waterway system operations. *Systems* 4, 23.
36. Rajesh, R. & Ravi, V. (2015) Supplier selection in resilient supply chains: a grey relational analysis approach. *Journal of Cleaner Production* 86, pp. 343–359.
37. Rolbiecki, R., Rydzykowski, W. & Wojewódzka-Król, K. (2007) *Transport wodny śródlądowy*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
38. Rozwój śródlądowych dróg wodnych w Polsce na lata 2016–2020 z perspektywą do 2030 (2016) Załącznik do uchwały Rady Ministrów z dnia 14 czerwca 2017, poz. 711.
39. Semenov, I.N. (2005) *Innovative Conceptions Impacts on Development system of Inland Shipping Network*. Materiały I Międzynarodowej Konferencji "Inland Shipping 2005" AM, Szczecin.
40. Semenov, I.N. (2006) *Inland waterways as a powerful tool for the further development of intermodality*. Coastal Ships & Inland Waterways II: International Conference London: The Royal Institution of Naval Architects, pp. 15–25.
41. Smoliński, A. (2014) *Klasyfikacja i porównanie metod klasycznej optymalizacji wielokryterialnej. Informatyczne systemy zarządzania*. Tom 5. Monografia pod red. K. Bzdyry, Koszalin.
42. Tabor, J. (2018) A grey-based decision-making approach to the improvement of OHS management system. *Polish Journal of Management Studies* 18(1), pp. 389–402.
43. Tabor, J. (2021) Ranking of management factors for safe maintenance system based on Grey Systems Theory. *Production Engineering Archives* 27(3), pp. 196–202.
44. Tan, Q., Farquharson, B., Chen, D. & Liu, J. (2014) An analysis of factors influencing the output value of unit sown area based on grey incidence analysis. *Grey Systems: Theory and Application* 4(1), pp. 56–71.
45. Tanaka, H. & Okada, A. (2019) Effects of market-based measures on a shipping company: using an optimal control approach for long-term modeling. *Research in Transportation Economics* 73, pp. 63–71.
46. Tołkacz, L. (2010) *Infrastruktura transport wodnego, Tom I. Infrastruktura transportu śródlądowego*. Wydanie elektroniczne, Szczecin.
47. Tołkacz, L. (2011) *Infrastruktura transport wodnego, Tom II. Infrastruktura transportu śródlądowego*. Wydanie elektroniczne, Szczecin.
48. Tzannatos, E., Tselentis, B. & Corres, A. (2016) An inland waterway freight service in comparison to land-based alternatives in South-Eastern Europe: energy efficiency and air quality performance. *Transport* 31, pp. 119–126.
49. Wang, Y., Liu, Q. & Bi, R. (2015) Grey incidence analysis on relationship between China's OFDI industry layout and industrial structure optimization. *IEEE International Conference on Grey Systems and Intelligent Services (GSIS)*, pp. 122–126, doi: 10.1109/GSIS.2015.7301841.
50. Wang, Y., Zio, E., Wei, X., Zhang, D. & Wu, B. (2019) A resilience perspective on water transport systems: the case of Eastern Star. *International Journal of Disaster Risk Reduction* 33, pp. 343–354.
51. Wiegmans, B. & Konings, J.W. (2015) Intermodal inland waterway transport: modelling conditions influencing its cost competitiveness. *The Asian Journal of Shipping and Logistics* 31, pp. 273–294.
52. Wojewódzka-Król, K. (2015) *Transport wodny śródlądowy. Funkcjonowanie i rozwój*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
53. Wojewódzka-Król, K. & Rolbiecki, R. (2014) *Transport wodny śródlądowy*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
54. Woś, K. & Han, M. (2017) *Żegluga Odrzańska jako element intermodalnych łańcuchów transportowych*. Szczecin: Akademia Morska w Szczecinie.
55. Xie, N., Hu, C. & Yin, S. (2016) Key indexes choosing approach of complex equipment's development cost based on grey incidence cluster model. *Grey Systems: Theory and Application* 6(1), pp. 110–123.
56. Załoga, E. (2017) Przesłanki i narzędzia promocji transportu wodnego śródlądowego w Unii Europejskiej. *Problemy Transportu i Logistyki* 1(37), pp. 323–333.
57. Zhang, M., Janic, M. & Tavasszy, L.A. (2015) A freight transport optimization model for integrated network, service, and policy design. *Transportation Research Part E* 77, pp. 61–76.
58. Zhu, J., Zhang, S., Chen, Y. & Zhang, L. (2016) A hierarchical clustering approach based on three-dimensional gray relational analysis for clustering a large group of decision makers with double information. *Group Decision and Negotiation* 25(2), pp. 325–354.
59. Żak, J., Jacyna-Gołda, I. & Wasiak, M. (2014) Effectiveness evaluation criteria of the functioning of the national transport system and its impact on the environment. In: *Simulation model to support designing a sustainable national transport system*. (Eds) Jacyna, M. & Wasiak, M.

Cite as: Tabor, J. (2022) Use of the grey incidence analysis in the inland waterway transport system assessment. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 72 (144), 57–64.