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A MULTIFACETED APPROACH TO ASSESSING INTERMODAL TRANSPORT

Summary. The article presents the issues of land intermodal transport, taking into account their impact on the natural environment. The subject of the research is the use of the ELECTRE I method as a decision support tool in the assessment of various variants of transport, taking into account intermodal transport, i.e., transport on the initial and final sections of the route with the use of road transport and transport in the middle longest section by rail transport. This significantly reduces the emission of harmful compounds emitted into the atmosphere by the transport industry. In connection with the above, research on the possibility of choosing transport routes using mixed modes of land transport has been presented. The analyzed transport from point A to destination B considers two reloading operations at the land intermodal terminals. For each of the variants, indicators related to emissions from fuel consumption, the total time and cost of the process, the share of rail transport in the entire process, and the distance of road transport were

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calculated. The final analysis of the results shows that the following parameters had the most significant impact on the course of the research: the level of carbon dioxide emissions into the atmosphere and the total cost of the process for a given variant. Based on the conducted research, it can be concluded that the variant of transporting cargo from Rybnik to Świdnik with reloading at the PCC Intermodal terminals in Gliwice and the Lublin Container Terminal turned out to be the most advantageous solution.

Keywords: intermodal transport, natural environment, multi-criteria assessment, ELECTRE I method

1. INTRODUCTION

Modal transport refers to the way of organizing transportation that uses only one type of transport vehicle during the transportation process. Modal transport has its advantages, such as simple planning and execution, due to the limited number of handling operations and point infrastructure elements involved in its implementation. An increasingly good argument is also the fact that modal transport puts greater pressure on the natural environment (Viorela-Georgiana, 2015; Mostert, Caris & Limbourg, 2017).

On the other hand, intermodal transport uses different types of transport vehicles to transport cargo, allowing for the optimization of cargo flow, reduced transport time, reduced costs, and, at the same time, reducing the impact on the natural environment (Viorela-Georgiana, 2015). It combines different means of transport into one system, allowing goods to be transported from place to place without the need for handling and directly to the destination. Practically, during the entire transport process in intermodal transport, the cargo is in one transport package: the Intermodal Loading Unit (ILU). The most commonly used ILUs are standardized containers and swap bodies, but an ILU can also be the entire road vehicle (Nehring, et al., 2021; Nader, Kostrzewski & Kostrzewski, 2017).

Intermodal transport plays a significant role in the global economy. Well-planned intermodal transport involves the efficient use of different modes of transport, resulting not only in reduced economic costs but also a minimized environmental impact (Dărăbanț, Ștefănescu & Crișan, 2012; Wiśnicki & Dyrda, 2015; Čižiūnienė, Bureika & Matijošius, 2022). However, it is important to note that despite its lower environmental impact compared to traditional transport methods, intermodal transport still generates real environmental impact due to the size of its market (Čižiūnienė, Bureika & Matijošius, 2022).

According to data from the World Health Organization (WHO), the United Nations (UN), and the International Energy Agency (IEA), transportation accounts for about 23% of global human-induced carbon dioxide (CO_2) emissions. Road transport is identified as one of the main sources of air pollutants, such as nitrogen oxides (NO_x), sulfur oxides (SO_x), and PM2.5 particles (IEA, 2022; WHO, 2022; UN, 2023).

Transportation has a significant impact on climate change and puts pressure on the natural environment. Its effects can be seen in:

a) the state of water and air, among other things, through the production of pollutants,
b) its impact on the landscape through the development of transportation infrastructure,
c) its impact on living organisms through the narrowing of natural habitats as well as accidents involving animals.

In addition, the indirect impact of the industry necessary for the functioning of transportation (the exploitation of natural resources and the manufacturing sector) should also be considered.

The authors (Ge, Shi & Wang, 2020) present the impact of intermodal transportation on the environment and identify areas of intermodal transportation organization that particularly limit the pressure on nature exerted by transportation. Two main types of intermodal terminals can be distinguished: maritime terminals and land terminals. Both types of facilities allow for the handling and servicing of intermodal units, but they differ significantly in the way certain processes are carried out. The article focuses on land terminals (Nehring, et al., 2021).

The key areas for the efficiency of organizing intermodal transport processes, with particular emphasis on reducing the impact on the natural environment, have been identified. Other indicators were also taken into account (including costs and implementation time) because, in real transport conditions, it is not possible to exclude them when choosing the method of transport process implementation. In order to enable a reliable comparison of different transport variants, even in the area of several available intermodal solutions, the ELECTRE I multicriteria assessment method was applied.

The article's second point provides a literature review that presents the state of knowledge in areas related to the topic. Then, the focus is on identifying possible indicators for evaluating intermodal transport (point 3). Point 4 presents a multi-criteria assessment method and a case study example. The article concludes with the conclusions section (section 5).

2. LITERATURE REVIEW

2.1. Organization of the intermodal transport

The first area covers general issues related to the organization of intermodal transport and its current condition. The first article to mention is Pencheva, et al. (2022). The authors addressed the issue of organizing freight intermodal transport, taking into account both current market trends and other factors. In a concise and informative manner, while presenting results that provide an overview of the situation in the studied area, Cagnina, et al. (2019) focused on the aspects of environmental protection and emissions related to intermodal transport. In this area, it is also worth mentioning the article by Čižiūnienė, Bureika & Matijošius (2022).

The importance of intermodal transport in sustainable development was emphasized by Viorela-Georgina (2015). The author thoroughly analyzed not only the economic aspects but also those related to ecology. The impact of transport on the natural environment was described. Similar approaches were taken by Mostret, et al. (2017), who reanalyzed both the economic aspect of proper intermodal transport organization and the one related to the environment (air pollution emissions). In addition to obvious aspects of transport's impact on the environment, such as emissions of pollutants, factors such as noise pollution can also be highlighted, as discussed by Danilevičius, Karpenko & Křivánek (2023).

Some authors have not only limited themselves to studying the impact of intermodal transport on the natural environment based on reports or available data but have also developed this issue with their analyses and models, such as mathematical ones. An example can be found in Ramalho & Santos (2021). In contrast, Ge, Shi, & Wang (2020) demonstrate that not only the implementation of intermodal transport affects its efficiency but also all structures (including legislative ones) with which it is associated. The choice of intermodal transport was also addressed by Beškovnik & Golnar (2020) by conducting a multicriteria analysis of factors influencing the choice of a particular method of transport organization. One of the key factors described in this study is the impact on the environment and energy consumption.

2.2. Efficiency of intermodal transport

Many publications relate to issues related to the efficiency of intermodal transport and its impact on the environment. The efficiency of intermodal transport, with particular attention to the organization of the last stage of transport, has been analyzed by, among others, Bergqvist & Monios (2016). However, a larger number of publications address the broader concept of intermodal transport and even analyze the entire intermodal transport process. Despite the practically standardized nature of intermodal transport globally, individual markets may differ in terms of transport organization or work characteristics. Wiśnicki & Dyrda (2016) referred to the European market. There are also a number of publications referring to selected countries (Pekin, et al. (2013); Nader, Kostrzewski & Kostrzewski (2017); Ge, Shi, & Wang (2020)).

Publications described in the later part of the chapter also relate to environmental impact aspects, such as Jachimowski et al., (2018) and Tadić, et al. (2020). This indicates the importance of the issue.

Numerous reports, standards, and regulations can also be included in this group, which can be helpful, for example, in making decisions about the criteria used to evaluate the system. Expert knowledge and knowledge of the realities of operation are also necessary for evaluating the system or attempting to model and optimize it. Therefore, it is possible to refer to standards related to the use of containers (PNISO, 2018) and other types of intermodal units (IU, 2011), as well as types of intermodal wagons (UIC, 2011). Reports such as UIRR (2021) or UTK (2022), which refer to the results of intermodal transport and development trends or the current state (UTK, 2023), complete the picture of the state of intermodal transport.

2.3. Transport optimization

Another group of publications analyzed are articles related to optimization in intermodal transport. These publications allow for identifying potential areas for optimization and familiarizing oneself with their methods. A good starting point in this group are review articles such as Ambrosino, Asta & Crainic (2021). Although the authors focused their attention on maritime terminals, the publication addresses many important issues for the entire intermodal transport. Meanwhile, Jachimowski (2017) identified decision-making problems occurring in the organization of intermodal terminal work. Another review publication is Boysen, et al. (2012).

A group of significant factors affecting the functioning of intermodal transport was distinguished by Tadić, et al. (2020) with reference to the problem of the location and layout of the intermodal terminal. Wiese, et al. (2010) also referred to the issue of terminal layout. In addition, Tadić, et al. (2019) should be mentioned, where the same topic was addressed with consideration of terminal efficiency, and Kristić, et al. (2019), where the authors focused their attention only on the selection of internal transport means working in the intermodal terminal. This issue was further expanded by Ricci, et al. (2016). The authors once again addressed the key elements for the functioning of the terminal and the organization of their work.

Many publications focus not on the entire system but on optimization problems related to a selected element. These include Jachimowski et al. (2018), Nehring et al. (2021), and Heggen, Breakers & Caris (2018). The first of the mentioned publications refers to the way containers are stored in an intermodal terminal and, importantly, combines research results directly with their impact on the environment through the analysis of CO_2 emissions. The second and third focus on the strategy of loading intermodal trains and simultaneously emphasize their efficiency, seeking solutions that minimize labor intensity. Wang & Zhu (2019) applied a similar approach to optimizing processes in the terminal. Referring to the issue of intermodal train service, attention should be paid to the publication by Bruns and Knust (2012), which exceptionally clearly and comprehensively addresses this process.

Another significant area of optimization is the issue of organizing the work of transshipment equipment in the terminal. Not only the selection of their type but also the adoption of the appropriate work organization (e.g., designation of zones and work logic) can have a considerable impact on the terminal's efficiency. Li, Otto & Pesch (2018) and Boysen & Fliedner (2010) addressed this topic.

An important issue related to the organization of intermodal transport was discussed by Gnap et al. (2021). The authors analyzed the issue of locating the intermodal terminal, taking into account the location of other elements of infrastructure and their accessibility over time. There are more areas for optimization, as evidenced by publications such as Kuzmicz et al. (2019) analyzing the issue of the flow of empty containers, or Yung-Cheng et al. (2008), in which the author focused on optimizing the aerodynamics of the intermodal train.

2.4. Multi-criteria assessment methods

One of the last distinguished areas is the methods of assessing systems, with particular emphasis on multi-criteria decision-making methods that can be applied in the analyzed case. A decision support model in the case of using multiple evaluation criteria was discussed by Jacyna-Gołda and Izdebski (2017) using the example of selecting a location for a warehouse in a logistics network. A set of parameters for assessment and an optimization function were presented.

The issue indirectly related to multi-criteria assessment was undertaken by Izdebski et al. (2020). The authors addressed the issue of optimization within the supply chain using tools based on a set of criteria for its evaluation. A mathematical model of the system was built, and a genetic algorithm was used for optimization. Szczepański et al. (2019) applied computer modeling and simulation for optimization purposes, with a slightly different approach to the issue of locating logistics infrastructure.

Several basic methods used in decision-making situations requiring multi-criteria analysis (MCDM, multi-criteria decision-making) can be distinguished in the literature. Selected methods used by the authors include the AHP method and the MAJA method, which was used by Małachowski et al. (2021). Özcan, Çelebi & Esnaf (2011) also compared many of these methods. It is also worth mentioning the publication by Odu (2019), in which the author also addressed other assessment methods and classified them into three main groups (subjective weighting methods, objective weighting methods, and integrated weighting methods).

In scientific literature related to the fields of civil engineering and transportation, multicriteria methods are often used in decision-making situations related to the choice of transportation means or the location of infrastructure elements. An example of this is the already-mentioned publication by Lasota et al. (2023), where the authors used the Electre I and AHP methods to analyze the selection of means of transport for oversized transport. Location issues of logistics facilities were addressed by, among others, Özcan, Çelebi & Esnaf (2011) and Ocampo et al. (2020) using the TOPSIS method. Multicriteria analysis methods are also widely used in the latest publications related to current issues in the transport market and related industries. Hamarcu & Eren (2022) analyzed the use of electric vehicles in public transportation using the MOORA and TOPSIS methods. On the other hand, Olivos & Ceceres (2022) addressed the problem of the placement of emergency ambulance services, specifically in Chile, using a case-study approach. An interesting combination of using the SAW multi-criteria assessment method in conjunction with an appropriate algorithm was used by Gołębiowski et al. (2019).

2.5. Impact of transport on the natural environment

The impact of transportation on the environment is undeniable. The transportation industry has a significant impact on the natural environment, including climate, air quality, water quality, soil quality, landscape changes, and energy consumption (IEA, 2022; WHO, 2022; UN, 2023). The following are the main effects of transportation on the natural environment:

a) Greenhouse gas emissions.
b) Air pollution (emissions).
c) Air pollution (wear and tear of components).
d) Water pollution.
e) Soil pollution.
f) Landscape changes.
g) Energy consumption.

As awareness of the detrimental effects on the environment has increased, efforts have been made to limit the negative impact of the transportation industry. Examples of such actions include developing more efficient and cleaner transportation technologies (such as developing electric vehicles or those powered by renewable energy sources), increasing the use of public transportation, promoting cycling and walking, and reducing energy consumption through more sustainable planning of cities and transportation infrastructure (Cieśla, Sobota & Jacyna, 2020, Jacyna et al., 2021).

Unfortunately, not all of the recommended ecological solutions can be easily applied in the case of freight or intermodal transport. Limitations may arise mainly due to the fact that more environmentally friendly new technologies are often still in the development phase, and their implementation generates numerous constraints. Another aspect may be the cost of purchasing modern infrastructure and superstructure. An important factor frequently remains the reluctance of decision-makers (e.g., entrepreneurs) to invest in new technologies, and sometimes it seems more beneficial in the short term to stick to conventional solutions. Numerous initiatives are also being undertaken to support ecological solutions in transport.

In addition to ecological factors, numerous benefits of intermodal transport related to the environment can also be observed. Among others, this includes the reduction of traffic congestion, which directly affects air quality, especially in large urban areas, and also reduces the stress of their inhabitants. By reducing the number of vehicles, it is also possible to reduce the number of road accidents. All of these factors contribute to reducing the impact of transport on the environment.

At the current stage of knowledge, research rarely provides clear indications of how much fewer emissions intermodal transport produces compared to other ways of organizing transport. This is probably because the impact on the environment depends on many factors, and significant differences (e.g., in greenhouse gas emissions) can be observed even with the same way of organizing transport, but only when elements such as transport distance, the specific nature of the transport order, the condition of the vehicle fleet, or the type of fuel used are changed. However, it is possible to compare and evaluate several possible ways of carrying out a task when its data is known. Due to the factors described above, important information on emissions can be found in publications such as Wasiak, Niculescu & Kowalski (2020), where authors analyzed pollution emissions from different types of transport modes.

The importance of the issue of the impact of transport on the natural environment and the quality of human life can also be seen through the increasing number of publications on this issue. Some of them refer to the problem in a general way, while others focus on specific issues. It is also emphasized that this topic is increasingly becoming an area of interest for decision-making and management institutions in given areas (Jacyna et al., 2021).

3. INDICATORS FOR MULTI-CRITERIA EVALUATION OF INTERMODAL TRANSPORT

Based on the data and assumptions described below, indicators for evaluating intermodal transport organizations have been defined. Along with a brief description and key parameters, they are presented in Table 1. Different weights of significance have been assigned to the criteria in the table for the two examined approaches:

a) approach 1 is an environmentally friendly option in line with current trends and recommendations,
b) approach 2 is an option where key factors are costs and time of implementation.

In the following part of the article, the impact of each approach on the results will be analyzed.

Table 2 presents the basic data used in calculations for indicators W1-W6. Figure 1 schematically shows the process organizations with markings highlighted in Table 3.

Tab. 1

Chosen indicators for the assessment of intermodal transport

No	**Indicator**	**Characteristics**	**Unit**	**Weight**	
				Approach 1	**Approach 2**
W1	Emissions due to fuel consumption	destimulant	[m^3 CO_2]	3	2
W2	Emissions from other energy sources	destimulant	[m^3 CO_2]	3	2
W3	The total execution time of the process	destimulant	[h]	2	3
W4	The total cost of the process	destimulant	[PLN]	2	3
W5	Share of rail transport in total transport	stimulant	[%]	1	1
W6	Total road transport distance	destimulant	[km]	1	1

Tab. 2

Basic data and symbols for calculations of indicators W1-W6

No	Mark	Conditions	Description
1	A_i	$A_i \in \boldsymbol{A}, i = \{1, 2, 3, \ldots., I\};$	loading point (start point)
2	$P1_j$	$P1_j \in \boldsymbol{P}, j = \{1, 2, 3, \ldots., J\};$	first reloading point (intermodal terminal)
3	$P2_j$	$P2_j \in \boldsymbol{P}, j = \{1, 2, 3, \ldots., J\};$	second reloading point (intermodal terminal)
4	B_k	$B_k \in \boldsymbol{B}, k = \{1, 2, 3, \ldots., K\};$	unloading point (destination point)
5	$D1$	$D1 \in \boldsymbol{D1},$ $\boldsymbol{D1} = \left[D1\left(A_i, P1_j\right)\right]_{I\times J};$	the first section of transport from loading point to the first intermodal terminal
6	$D2$	$D2 \in \boldsymbol{D2},$ $\boldsymbol{D2} = \left[D2\left(P1_j, P2_j\right)\right]_{J\times J};$	second (middle) section of transport between terminals
7	$D3$	$D3 \in \boldsymbol{D3},$ $\boldsymbol{D3} = [D3(P2_j, B_k)]_{J\times K}$	the third section of transport from the terminal to the unloading point
8	S_{D1}	$S_{D1} \in \boldsymbol{S},$ $\boldsymbol{S} = \{S1, S2, S3, \ldots., So\};$	road vehicle assigned to a road section $D1$
10	S_{d3}	$S_{D3} \in \boldsymbol{S},$ $\boldsymbol{S} = \{S1, S2, S3, \ldots., So\};$	road vehicle assigned to a road section $D3$
11	K_{d2}	$K_{D2} \in \boldsymbol{K},$ $\boldsymbol{K} = \{K1, K2, K3, \ldots., Kp\};$	rail vehicle assigned to a road section $D2$
12	U_{P1}	$U_{P1} \in \boldsymbol{U},$ $\boldsymbol{U} = \{U1, U2, U3, \ldots., Ur\};$	loading device assigned to the terminal $P1$
13	U_{P2}	$U_{P2} \in \boldsymbol{U},$ $\boldsymbol{U} = \{U1, U2, U3, \ldots., Ur\};$	loading device assigned to the terminal $P2$
14	$L_{OP(P1)}$	$L_{OP(P1)} \in \boldsymbol{N};$	number of operations performed in the $P1_j$
15	$L_{OP(P2)}$	$L_{OP(P1)} \in \boldsymbol{N};$	number of operations performed in the $P2_j$

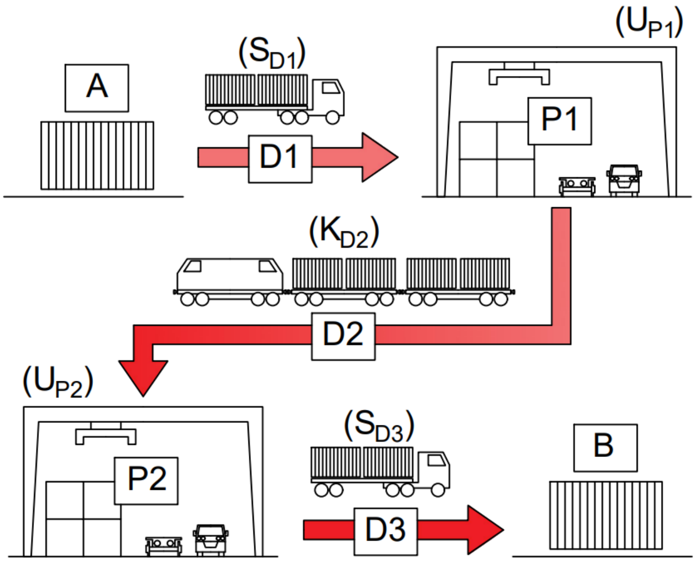

Fig. 1. Scheme of transport organization using the markings from Tab. 2

For the clarity of further research, for each considered variant n ($N = \{1, 2, 3, \dots, n, \dots, N\}$, where N denotes the number of the considered variants):
$W1_n$ – Emissions due to fuel consumption for the n-th variant:

$$W1_n = E_{S(D1)}\left(\frac{\left(d1(A_i,P1_j)\cdot z_s(S_{D1})\right)}{100}\right) + E_{S(D3)}\left(\frac{\left(d3(P2_j,B_k)\cdot z_s(S_{D3})\right)}{100}\right) + E_{K(D2)}\left(\frac{d2(P1_j,P2_j)\cdot z_K(K_{D2})}{100}\right) + E_{U(P1)}\left(L_{OP(P1)}\cdot z_U(U_{P1})\right) + E_{U(P2)}\left(L_{OP(p2)}\cdot z_U(U_{P2})\right)\ [\text{m}^3\ \text{CO}_2], \tag{1}$$

Where:
$d1(A_i, P1_j)$ –road from A_i to $P1_j$ (road transport) [km]: $d1 \in d1,\ d1 = [d1(A_i, P1_j)]_{I\times J}$,
$d2(P1_j, P2_j)$ – road from $P1_j$ to $P2_j$ (rail transport) [km]: $d2 \in d2,\ d2 = [d2(P1_j, P2_j)]_{J\times J}$,
$d3(P2_j, B_k)$ – road from $P2_j$ to B_k (road transport) [km]: $d3 \in d3,\ d3 = [d3(P2_j, B_k)]_{J\times K}$,
$z_s(S_{D1})$ – fuel consumption for a road vehicle S_{D1} [L/100km]: $z_s(S_{D1}) \in z_s(S)$,
$z_s(S_{D3})$ – fuel consumption for a road vehicle S_{D3} [L/100km]: $z_s(S_{D3}) \in z_s(S)$,
$z_K(K_{D2})$ – fuel consumption for a railway vehicle K_{D2} [L/100km]: $z_K(K_{D2}) \in z_K(K)$,
$z_U(U_{P1})$ – fuel consumption for the loading device U_{P1} [L/operation]: $z_U(U_{P1}) \in z_U(U)$,
$z_U(U_{P2})$ – fuel consumption for the loading device U_{P2} [L/operation]: $z_U(U_{P2}) \in z_U(U)$,
$E_{S(D1)}$ –CO_2 emission emissions from the 1 liter of fuel by vehicle S_{D1} [m^3 CO_2/L]: $E_{S(D1)} \in E_S(S)$,
$E_{S(D3)}$ – CO_2 emission emissions from the 1 liter of fuel by vehicle S_{D3} [m^3 CO_2/L]: $E_{S(D2)} \in E_S(S)$,
$E_{K(D2)}$ – CO_2 emission emissions from the 1 liter of fuel by vehicle K_{D2} [m^3/L]: $E_{K(D2)} \in E_K(K)$,
$E_{U(P1)}$ – CO_2 emission from the 1 liter of fuel by the loading device U_{P1} [m^3 CO_2/L]: $E_{U(P1)} \in E_U(U)$,
$E_{U(P2)}$ – CO_2 emission from the 1 liter of fuel by the loading device U_{P2} [m^3 CO_2/L]: $E_{U(P2)} \in E_U(U)$.

$W2_n$ – Emissions from other energy sources for the n-th variant (applies to vehicles powered by electricity or an alternative fuel/energy source):

$$W2_n = E^*_{S(D1)}\left(\frac{d1(A_i,P1_j)}{100}\right) + E^*_{S(D3)}\left(\frac{d3(P2_j,B_k)}{100}\right) + E^*_{K(D2)}\frac{\left(d2(P1_j,P2_j)\right)}{100} + E^*_{U(P1)}\left(L_{OP(P1)}\right) + {} + E^*_{U(P2)}\left(L_{OP(p2)}\right)\ [\text{m}^3\ \text{CO}_2], \tag{2}$$

Where:
$E^*_{S(D1)}$ – emission CO_2 per 100 km of route from the consumption of electricity or alternative fuel by a road vehicle S_{D1} [m^3 CO_2/100km]: $E^*_{S(D1)} \in E^*_S(S)$,
$E^*_{S(D3)}$ – per 100 km of route from the consumption of electricity or alternative fuel by a road vehicle S_{D3} [m^3 CO_2/100km]: $E^*_{S(D3)} \in E^*_S(S)$,
$E^*_{K(D2)}$ – emission CO_2 per 100 km of route from the consumption of electricity or alternative fuel by a railway vehicle K_{D2} [m^3 CO_2/100km]: $E^*_{K(D2)} \in E^*_K(K)$,

$E^*_{U(P1)}$ – emission CO$_2$ per operation from the consumption of electricity or alternative fuel by a loading device U_{P1} [m^3 CO$_2$/operation]: $E^*_{U(P1)} \in E^*_U(U)$,
$E^*_{U(P2)}$ – emission CO$_2$ per operation from the consumption of electricity or alternative fuel by a loading device U_{P2} [m^3 CO$_2$/operation]: $E^*_{U(P2)} \in E^*_U(U)$.

$W3_n$ – The total execution time of the process for the *n*-th variant:

$$W3_n = t1\left(A_i, P1_j\right) + t3\left(P2_j, B_k\right) + t2\left(P1_j, P2_j\right) + t_o(A_i) + t_o(B_k) + t_p\left(P1_j\right) + \\ + t_p(P2_j) \ \ [\mathrm{m}^3\ \mathrm{CO}_2], \tag{3}$$

Where:
$t1\left(A_i, P1_j\right)$ – cargo transit time from A_i to $P1_j$ [h]: $t1 \in t1, t1 = [t1(A_i, P1_j)]_{I\times J}$,
$t3\left(P2_j, B_k\right)$ – cargo transit time $P2_j$ to B_k [h]: $t3 \in t3, t3 = [t3(P1_j, P2_j)]_{J\times J}$,
$t2\left(P1_j, P2_j\right)$ – cargo transit time $P1_j$ to $P2_j$ [h]: $t2 \in t2,\ t2 = [t2(P2_j, B_k)]_{J\times K}$,
$t_o(A_i)$ –average cargo handling time in A_i [h]: $t_o(A_i) \in t_o,\ t_o = [t_o(A_i)]_{I\times 1}$,
$t_o(B_k)$ – average cargo handling time in B_k [h]: $t_o(B_k) \in t_o,\ t_o = [t_o(B_k)]_{K\times 1}$,
$t_p\left(P1_j\right)$ – average load stay time in $P1_j$ [h]: $t_p\left(P1_j\right) \in t_p, t_p = [t_p(P1_j)]_{J\times 1}$,
$t_p(P2_j)$ – average load stay time in $P2_j$ [h]: $t_p\left(P1_j\right) \in t_p, t_p = [t_p(P2_j)]_{J\times 1}$,

$W4_n$ – The total cost of the process for the *n*-th variant:

$$W4_n = CL + CE + CD \tag{4}$$

Where:
CL – costs resulting from fuel consumption [PLN],
CE – costs resulting from electricity and alternative fuels [PLN],
CD – additional costs resulting from the selection of shipping, collection and intermediate points [PLN].

$$CL = CL_{S(D1)}\left(\frac{\left(d1\left(A_i, P1_j\right)\cdot z_S(S_{D1})\right)}{100}\right) + CL_{S(D3)}\left(\frac{\left(d3\left(P2_j, B_k\right)\cdot z_S(S_{D3})\right)}{100}\right) + \\ CL_{K(D2)}\left(\frac{d2\left(P1_j, P2_j\right)\cdot z_K(K_{D2})}{100}\right) + CL_{U(P1)}\left(L_{OP(P1)} \cdot z_U(U_{P1})\right) + CL_{U(P2)}\left(L_{OP(p2)} \cdot \\ z_U(U_{P2})\right) \ \ [\mathrm{PLN}], \tag{5}$$

Where:
$CL_{S(D1)}$ – the price of a liter of fuel for a road vehicle S_{D1} [PLN/L]: $CL_{S(D1)} \in CL_S$,
$CL_{S(D3)}$ – the price of a liter of fuel for a road vehicle S_{D3} [PLN/L]: $CL_{S(D3)} \in CL_S$,
$CL_{K(D2)}$ – the price of a liter of fuel for a railway vehicle K_{D2} [PLN/L]: $CL_{K(D2)} \in CL_K$,
$CL_{U(P1)}$ – the price of a liter of fuel for the loading device U_{P1} [PLN/L]: $CL_{U(P1)} \in CL_U$,
$CL_{U(P2)}$ – the price of a liter of fuel for the loading device U_{P2} [PLN/L]: $CL_{U(P1)} \in CL_U$,

$$CE = CE^*_{S(D1)}\left(\frac{d1\left(A_i, P1_j\right)}{100}\right) + CE^*_{S(D3)}\left(\frac{d3\left(P2_j, B_k\right)}{100}\right) + CE^*_{K(D2)}\frac{\left(d2\left(P1_j, P2_j\right)\right)}{100} + \\ CE^*_{U(P1)}\left(L_{OP(P1)}\right) + CE^*_{U(P2)}\left(L_{OP(p2)}\right) \ \ [\mathrm{PLN}], \tag{6}$$

Where:
$CE^*_{S(D1)}$ – price per 100km of electricity or alternative fuel for vehicle S_{D1} [PLN/100km]: $CE^*_{S(D1)} \in CE^*_S$,
$CE^*_{S(D3)}$ – price per 100km of electricity or alternative fuel for vehicle S_{D3} [PLN/100km]: $CE^*_{S(D3)} \in CE^*_S$,
$CE^*_{K(D2)}$ – price per 100km of electricity or alternative fuel for vehicle K_{D2} [PLN/100km]: $CE^*_{K(D2)} \in CE^*_K$,
$CE^*_{U(P1)}$ – cost per operation of electricity or alternative fuel for the device U_{P1} [PLN/operation]: $CE^*_{U(P1)} \in CE^*_U$,
$CE^*_{U(P2)}$ – cost per operation of electricity or alternative fuel for the device U_{P2} [PLN/operation]: $CE^*_{U(P2)} \in CE^*_U$,

$$CD = \Big(CD(A_i) + CD(B_k) + CD\big(P1_j\big) + CD\big(P2_j\big)\Big) + \big(CD(S_{D1}) + CD(S_{D3}) + CD(K_{D2}) + CD(U_{P1}) + CD(U_{P2})\big) + \Big(CD\big(A_i, P1_j\big) + CD\big(P2_j, B_k\big) + CD\big(P1_j, P2_j\big)\Big) \text{ [PLN]}, \tag{7}$$

Where:
$CD(A_i)$ – additional cost resulting from the choice of A_i point [PLN], $CD(A_i) \in CD$,
$CD(B_k)$ – additional cost resulting from the choice B_k point [PLN], $CD(B_k) \in CD$,
$CD\big(P1_j\big)$ – additional cost resulting from the choice $P1_j$ point [PLN], $CD\big(P1_j\big) \in CD$,
$CD\big(P2_j\big)$ – additional cost resulting from the choice $P2_j$ point [PLN], $CD\big(P2_j\big) \in CD$,
$CD(S_{D1})$ – additional cost resulting from the choice $D1$ route [PLN], $CD(S_{D1}) \in CD$,
$CD(S_{D3})$ – additional cost resulting from the choice $D2$ route [PLN], $CD(S_{D3}) \in CD$,
$CD(K_{D2})$ – additional cost resulting from the choice $D3$ route [PLN], $CD(K_{D2}) \in CD$,
$CD(U_{P1})$ – additional cost resulting from the choice $P1$ point [PLN], $CD(U_{P1}) \in CD$,
$CD(U_{P2})$ – additional cost resulting from the choice $P2$ point [PLN], $CD(U_{P2}) \in CD$,
$CD\big(A_i, P1_j\big)$ – additional cost resulting from the route choice from A_i to $P1_j$ [PLN], $CD\big(A_i, P1_j\big) \in CD$,
$CD\big(P2_j, B_k\big)$ – additional cost from the route choice from $P2_j$ to B_k [PLN], $CD\big(P2_j, B_k\big) \in CD$,
$CD\big(P1_j, P2_j\big)$ – additional cost from the route choice from $P1_j$ to $P2_j$ [PLN], $CD\big(P1_j, P2_j\big) \in CD$.

$W5_n$ – Share of rail transport in total transport for the *n*-th variant:

$$W5_n = \frac{d2\big(P1_j, P2_j\big)}{d1\big(A_i, P1_j\big) + d3\big(P2_j, B_k\big) + d2\big(P1_j, P2_j\big)} \cdot 100 \text{ [\%]}, \tag{8}$$

$W6_n$ – Total road transport distance for the *n*-th variant:

$$W6_n = d1\big(A_i, P1_j\big) + d3\big(P2_j, B_k\big) \text{ [km]}, \tag{9}$$

4. MULTI-CRITERIA ASSESSMENT METHOD

4.1. Assumptions for the case study example

It is assumed that each of the considered variants is characterized by similar parameters regarding the possibility of handling a given cargo in a specified quantity or transport safety. This principle also applies to means of transport – the first (starting point → intermediate point) and the last phase (intermediate point → destination point) of transport can be carried out by any road vehicle if it is capable of transporting the given type of cargo. The same principle applies to rail transport between intermediate points and internal transport means in terminals.

For the purposes of the study, it is assumed that the problem under consideration is represented as a directed graph composed of vertices grouped into sets of starting, ending, and intermediate nodes. The parameters of the connections mapped by arcs are also known.

For the purposes of the article, a calculation example was conducted with the following assumptions:

- Similarly, to the transport assumptions, it is assumed that transport takes place in three main stages:
  a) Transport from the point of origin A to the first transshipment terminal P1.
  b) Transport between transshipment points P1 and P2.
  c) Transport from the second transshipment point P2 to the destination point B.
- The first and last phase of transport is carried out using intermodal transport. Transport in the middle, the longest stretch is carried out using rail transport.
- 30 standard 40’ containers are being transported.
- The place of origin is Rybnik, where the loaded containers are waiting for dispatch on road transport.
- The destination for the three intermodal units is Świdnik near Lublin.

Figures 2 and 3 show the place of loading (start point) and unloading (destination point) of ITUs as well as the intermodal terminals that can serve as the first transshipment point (transshipment from road to rail transport) and possible second transshipment points (transshipment from rail to road transport). Figure 4 shows the considered system schematically.

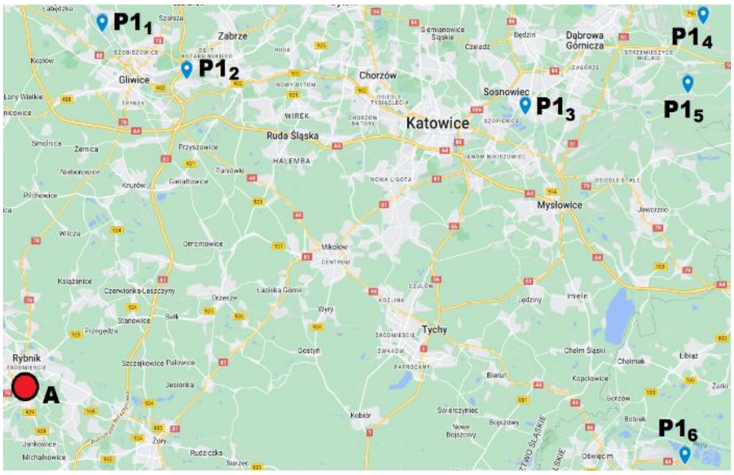

Fig. 2. Placement of loading point A and reloading points P1

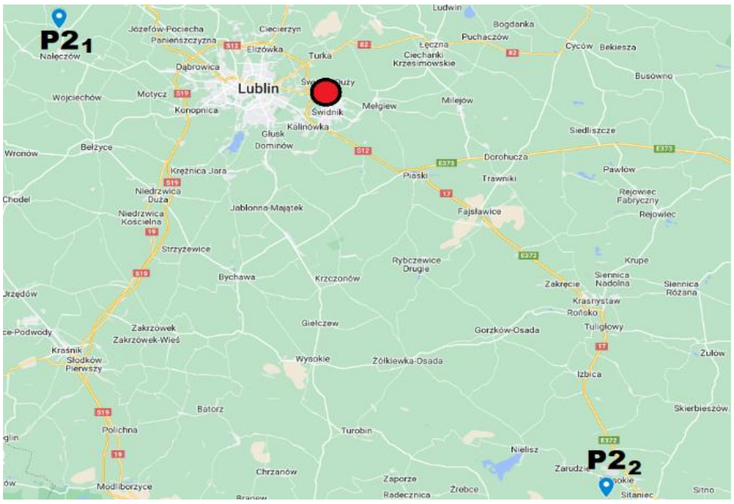

Fig. 3. Reloading points P2 and destination point B

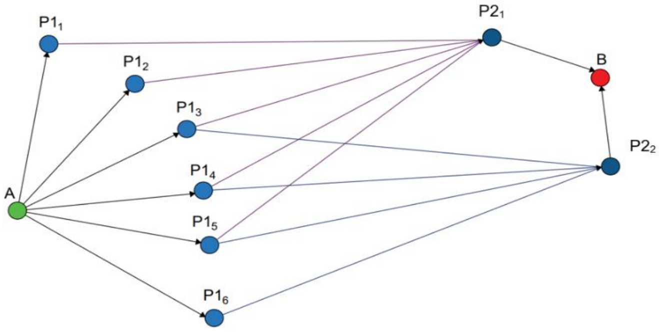

Fig. 4. Considered network of connections between points A, P1, P2 and B

Table 3 presents a list of points marked on Figures 2-4 and possible transportation routes (variants) in Table 4 and transport means for those variants (Table 5). Then, Table 6 shows other key parameters for calculating indicators W1-W6.

Tab. 3

List of points marked in Figures 2-4

Type of point	Mark	Description
Shipping point A	A	Rybnik city
Cargo handling point P1	$P1_1$	PCC Intermodal – Terminal PCC Gliwice
	$P1_2$	PKP Cargo Connect - Container Terminal - Gliwice
	$P1_3$	LAUDE SMART INTERMODAL S.A. Container Terminal in Sosnowiec
	$P1_4$	Metrans Terminal Dąbrowa Górnicza
	$P1_5$	Euroterminal Sławków Sp. z o.o.
	$P1_6$	Container Terminal Włosienica - Baltic Rail
Cargo handling point P2	$P2_1$	Lubelski Container Terminal - Drzewce
	$P2_2$	Logistic Center LAUDE SMART INTERMODAL S.A. in Zamość

Destination point B	B	Świdnik near Lublina city

Tab. 4

Considered variants of transport

Variant	D1			D2			D3		
	A	**P1**	**Distance d1 [km]**	**P1**	**P2**	**Distance d2 [km]**	**P2**	**B**	**Distance d3 [km]**
1	A	$P1_1$	40,2	$P1_1$	$P2_1$	446,9	$P2_1$	B	50,5
2	A	$P1_2$	35,7	$P1_2$	$P2_1$	434,2			
3	A	$P1_3$	63,9	$P1_3$	$P2_1$	454,9			
4				$P1_3$	$P2_2$	479,6	$P2_2$	B	82,5
5	A	$P1_4$	80,5	$P1_4$	$P2_1$	445,6	$P2_1$	B	50,5
6				$P1_4$	$P2_2$	417,5	$P2_2$	B	82,5
7	A	$P1_5$	82,9	$P1_5$	$P2_1$	429,1	$P2_1$	B	50,5
8				$P1_5$	$P2_2$	507,3	$P2_2$	B	82,5
9	A	$P1_6$	94,3	$P1_6$	$P2_2$	511,4			

Tab. 5

Transport means for the considered variants

Variant	Road vehicle (D1)	Loading device (P1)	Railway vehicle (D2)	Loading device (P2)	Road vehicle (D3)
1	VOLVO FH 12 500 + container trailer	Reachstacker	Bombardier Traxx – diesel locomotive	Reachstacker	VOLVO FH 12 500 + container trailer
2	Scania 500 S+ container trailer	Heavy front forklift	Siemens Vetron – diesel locomotive		
3	Mercedes-Benz 1845+ container trailer	Reachstacker	Alstrom Prima H3 – diesel locomotive	Heavy front forklift	Scania 500 S + container trailer
4			China Railways HXD3D – diesel locomotive		
5	Scania 500 S+ container trailer	Heavy front forklift	Bombardier Traxx – diesel locomotive	Reachstacker	VOLVO FH 12 500 + container trailer
6			China Railways HXD3D - diesel locomotive	Heavy front forklift	Scania 500 S + container trailer
7	VOLVO FH 12 500+ container trailer	Heavy front forklift	Siemens Vetron – diesel locomotive	Reachstacker	VOLVO FH 12 500 + container trailer
8			Bombardier Traxx – lspalinowa	Heavy front forklift	

9	Mercedes-Benz 1845+ container trailer	Reachstacker	Alstrom Prima H3 – diesel locomotive		Scania 500 S + container trailer

Due to the lack of use of electric vehicles and vehicles powered by alternative energy sources, the indicator regarding emissions from other sources of energy (W2) was omitted from the analysis. The parameters comprising this indicator were not defined because they did not affect the research conducted. Only vehicles powered by diesel fuel were selected for the analysis.

Tab. 6

Values of the other key parameters used during the calculations

Parameter	**Variants (chosen transport routes)**					
	a_1	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**
$z_s(S_{D1})$	32l/100km	30l/100km	28l/100km	30l/100km	32l/100km	28l/100km
$z_s(S_{D3})$	32l/100km	32l/100km	30l/100km	32l/100km	30l/100km	30l/100km
$z_K(K_{D2})$	48l/100km	49l/100km	47l/100km	48l/100km	49l/100km	50l/100km
$z_U(U_{P1})$	3l/operation	4l/operation	3l/operation	4l/operation	4l/operation	3l/operation
$z_U(U_{P2})$	3l/ operation	4l/ operation	3l/ operation	4l/ operation	3l/ operation	4l/ operation
$E_{S(D1)}$	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l
$E_{S(D3)}$	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l
$E_{K(D2)}$	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l
$E_{U(P1)}$	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l
$E_{U(P2)}$	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l	1,35 m^3/l
$t1(A_i, P1_j)$	0,57 h	0,53 h	0,78 h	0,97 h	0,98 h	1,25 h
$t3(P2_j, B_k)$	0,7 h	0,7 h	1,2 h	0,7 h	0,7 h	1,2 h
$t2(P1_j, P2_j)$	5,32 h	5,17 h	5,71 h	5,30 h	5,11 h	6,09 h
$t_o(A_i)$	0,33 h	0,3 h	0,27 h	0,25 h	0,3 h	0,28 h
$t_o(B_k)$	0,48 h	0,5 h	0,5 h	0,5 h	0,45 h	0,47 h
$t_p(P1_j)$	27 h	29 h	34 h	30 h	34 h	32 h
$t_p(P2_j)$	36 h	36 h	32 h	36 h	36 h	32 h
$CL_{S(D1)}$	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l
$CL_{S(D3)}$	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l
$CL_{K(D2)}$	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l
$CL_{U(P1)}$	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l
$CL_{U(P2)}$	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l	7,19 PLN/l
CD	Additional costs CD have been omitted due to lack of available data.					

4.2. Stages of the method

The choice of an appropriate decision analysis method depends on the characteristics of the problem we want to solve, as well as our preferences and goals. In the case of choosing the method of implementing intermodal transport, a reliable comparison of transportation options was made using the ELECTRE I multicriteria decision analysis. This method is based on the idea of pairwise comparison of options with respect to each criterion and the construction of preference relations based on the degree of agreement and disagreement between the options (Jacyna, 2022, Gołębiowski et al., 2019).

The process of using the ELECTRE I method consists of stages that have been described and presented below (Akram et al., 2022, Akram et al., 2020).

STAGE 1. Identification of the variants (alternatives) and assessment criteria, which are crucial for the decision problem (Table 7), and defining the weights of the criteria and values of the weighting coefficients (Table 8).

To conduct the analysis, 6 transport options for the segments were chosen:

a_1: A-$P1_1$-$P2_1$-B: (Rybnik – PCC Intermodal – Terminal PCC (Gliwice) – Lubelski Container Terminal (Drzewce) – Świdnik near Lublin),

a_2: A-$P1_2$-$P2_1$-B: (Rybnik – PKP Cargo Connect – Terminal Congenerous (Gliwice) – Lubelski Container Terminal (Drzewce) – Świdnik near Lublin),

a_3: A-$P1_3$-$P2_2$-B: (Rybnik – LAUDE SMART INTERMODAL S.A. Container Terminal in Sosnowiec – Logistic Center LAUDE SMART INTERMODAL S.A. in Zamość – Świdnik near Lublin),

a_4: A-$P1_4$-$P2_1$-B: (Rybnik – Metrans Terminal Dąbrowa Górnicza – Lubelski Container Terminal (Drzewce) – Świdnik near Lublin),

a_5: A-$P1_5$-$P2_1$-B: (Rybnik – Euroterminal Sławków Sp. Z o.o. – Lubelski Container Terminal (Drzewce) – Świdnik near Lublin),

a_6: A-$P1_6$-$P2_2$-B: (Rybnik – Container Terminal Włosienica – Baltic Rail – Logistic center LAUDE SMART INTERMODAL S.A. in Zamość – Świdnik near Lublin).

The results presented in the table correspond to the indicators that were developed in section 4.1 and are designated in chapter 3 of the article. The basic parameters used in the calculations are presented in Table 6. Table 7 shows the results of the calculations of indicators W1-W6. These are the alternatives considered in the example in the article.

Tab. 7

Results of the indicators W1-W6 assessment

Variant	**Indicator**				
	W1 [m^3 CO_2]	**W3 [h]**	**W4 [PLN]**	**W5 [%]**	**W6 [km]**
a_1	814,77	70,40	4339,42	83,13	90,70
a_2	971,50	72,20	5174,13	83,44	86,20
a_3	847,87	74,46	4515,71	76,61	146,40
a_4	991,17	73,72	5278,88	77,28	131,00
a_5	907,11	77,54	4831,23	76,28	133,40
a_6	981,25	73,29	5226,08	74,31	176,80

Tab. 8

Results of the variants' assessment

Variant	Indicator				
	W1	W3	W4	W5	W6
a_1	6	6	6	5	5
a_2	3	5	3	6	6
a_3	5	2	5	3	2
a_4	1	3	2	4	4
a_5	4	1	4	2	3
a_6	2	4	1	1	1
Weight	0,30	0,19	0,28	0,10	0,13
Tresholds for weighting coefficients	2	4	1	3	2

STAGE 2. Discordance matrix Z_n **construction**. Concordance tests were developed for pairs of decision alternatives (transport routes) that were determined based on individual evaluation criteria. Tables 9 and 10 present the binary matrix Z1 for the W1 indicator and Z3 for the W3 indicator, whose elements are $z(a_i, a_j)$. Similarly, calculations of concordance tests were carried out for the remaining indicators.

Tab. 9

Concordance test for the W1 indicator

Matrix Z_1	a_1	a_2	a_3	a_4	a_5	a_6
a_1	1	1	1	1	1	1
a_2	0	1	0	1	0	1
a_3	0	1	1	1	1	1
a_4	0	0	0	1	0	0
a_5	0	1	0	1	1	1
a_6	0	0	0	1	0	1

Tab. 10

Concordance test for the W3 indicator

Matrix Z_3	a_1	a_2	a_3	a_4	a_5	a_6
a_1	1	1	1	1	1	1
a_2	0	1	1	1	1	1
a_3	0	0	1	0	1	0
a_4	0	0	1	1	1	0
a_5	0	0	0	0	1	0
a_6	0	0	1	1	1	1

Then, based on the following equation, the values of the concordance coefficients were estimated:

$$z(a_i, a_j) = w_1 Z_1(a_i, a_j) + w_2 Z_2(a_i, a_j) + w_3 Z_3(a_i, a_j) + w_4 Z_4(a_i, a_j) + w_5 Z_5(a_i, a_j) \quad (10)$$

The calculations were compiled in Table 11. Taking into account the calculated values and the concordance threshold at the level of *s=0.57*, the membership of the concordance indicators was determined in binary form, which is presented in Table 12.

Tab. 11

Concordance coefficients values

Matrix Z	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**
a_1	1	0,77	1	1	1	1
a_2	0,23	1	0,42	1	0,42	1
a_3	0	0,58	1	0,58	0,87	0,81
a_4	0	0	0,42	1	0,42	0,51
a_5	0	0,58	0,13	0,58	1	0,81
a_6	0	0	0,19	0,49	0,19	1

Tab. 12

Concordance matrix in the binary form

Matrix C	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**
a_1	1	1	1	1	1	1
a_2	0	1	0	1	0	1
a_3	0	1	1	1	1	1
a_4	0	0	0	1	0	0
a_5	0	1	0	1	1	1
a_6	0	0	0	0	0	1

STAGE 3. Discordance matrix N_n **construction**. The discordance condition was verified for pairs of alternatives that satisfy the concordance condition. The analysis was carried out based on the following formula:

$$g_k(a_i) + v_k[g_k(a_i)] \geq g_k(a_j) \qquad (11)$$

where: $g_k(a_i)$ – assessment criterion.

In the Tables 13 and 14 example calculations for the chosen indicators are presented.

Tab. 13

Discordance test for the W1 indicator

Matrix N_1	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**
a_1	0	0	0	0	0	0
a_2	-	0	-	0	-	0
a_3	-	0	0	0	0	0
a_4	-	-	-	0	-	-
a_5	-	0	-	0	0	0
a_6	-	-	-	-	-	0

Tab. 14

Discordance test for the W5 indicator

Matrix N_5	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**
a_1	0	0	0	0	0	0
a_2	-	0	-	0	-	0
a_3	-	0	0	0	0	0
a_4	-	-	-	0	-	-
a_5	-	1	-	0	0	0
a_6	-	-	-	-	-	0

Similarly, calculations were performed for the remaining discordance tests. After verifying the discordance condition for all indicators, a summary of the set of discordances N in the form of a binary matrix was prepared (Table 15).

Tab. 15

Discordance matrix in the binary form

Matrix N	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**
a_1	0	0	0	0	0	0
a_2	-	0	-	0	-	0
a_3	-	1	0	0	0	0
a_4	-	-	-	0	-	-
a_5	-	1	-	0	0	0
a_6	-	-	-	-	-	0

STAGE 4. Outranking relations designation. The outranking relation for a pair of alternatives (a_i, a_j) occurs when both the concordance and discordance conditions are simultaneously fulfilled (a value of one is placed). Otherwise, a value of zero is entered. The mentioned outranking relation P (Table 16) was determined based on the tables of discordance and concordance matrices in binary form (Table 12 and Table 15).

Tab. 16

Designated elevation relations

Matrix P	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**
a_1	1	1	1	1	1	1
a_2	0	1	0	1	0	1
a_3	0	0	1	1	1	1
a_4	0	0	0	1	0	0
a_5	0	0	0	1	1	1
a_6	0	0	0	0	0	1

STAGE 5. Dependency graph between the considered decision variants. The graph was constructed using the determined outranking relations. The alternatives placed on the highest level are not outranked by any other alternative. On the second level, there are alternatives that

are outranked only by the alternatives on the first level. Similarly, the segregation of subsequent alternatives was performed.

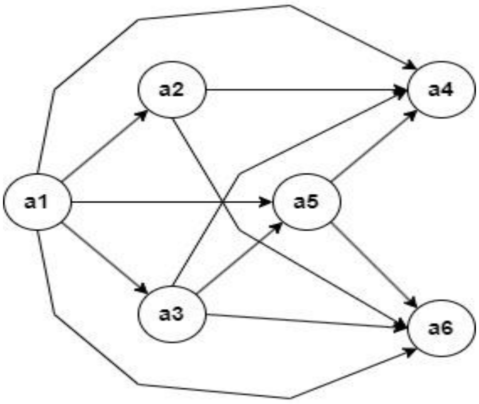

Fig. 5. Dependency graph between the considered decision variants

STAGE 6. Final ranking construction. Based on the conducted analysis of the optimal selection of transportation routes using the ELECTRE I method, a ranking of decision alternatives was made from the best to the worst. The scale of assigned ratings for the alternatives ranges from 1 to 5, with the most favorable alternative assigned a value of 1, while the worst alternative is assigned a value of 5.

Tab. 17

Final ranking for the considered variants

Decison variant	Preferred choice
a_1	1
a_2	3
a_3	2
a_4 *	5
a_5	4
a_6 *	5

* Based on the results of the method used, it was assumed that variants a_4 and a_6 are at the same level of choice.

5. SUMMARY

The article focuses on the impact of intermodal transport on the natural environment. The first part presents an analysis of the literature, which refers to the issue of the organization of intermodal transport and the efficiency and optimization of its transport. The methods of multi-criteria decision-making and the impact of transport on the natural environment, which was a significant aspect from the research's perspective, were also characterized.

In the second part of the article, six indicators relating to the assessment of intermodal transport efficiency were described. The basic assumptions of the system in which the transport was carried out were also defined. The first indicator concerned emissions from fuel consumption. The calculations included road distances between individual points, taking into account road and rail transport. From the point of view of the research problem, it was also important to determine fuel consumption and CO_2

Emissions from the consumption of 1 liter of fuel by road and rail vehicles. Another indicator is emissions from other energy sources. It was defined as vehicles powered by electricity or an alternative fuel or energy source. It was omitted from the analysis because the paper analyzes the transport performed on the basis of vehicles powered by diesel oil. The calculation of the total time of the process, the total cost of the process, and the total road transport distance are also presented. The last indicator is the share of rail transport in total transport.

The third part of the publication presents a multi-criteria evaluation of transport using the ELECTRE I method. It was assumed that the first and last phases of transport were carried out using road transport. Transport in the middle, the longest section, is carried out using rail transport. For the analysis of the example presented in the article, six decision variants were selected and evaluated. The ELECTRE I method made it possible to take into account both qualitative and quantitative criteria, which is particularly important in the case of decision-making problems in which the choice of the method of carrying out the transport process should be made. In addition, the analyzed method allows for the definition of weights for various criteria, which allows for their hierarchization and the determination of their relative importance. This results in a more accurate and balanced evaluation of the variants. The method is relatively easy to implement. This means that it can be applied to many different decision problems. However, it requires some knowledge of decision theory and the ability to work with calculation spreadsheets and basic databases.

Analyzing the final results, variant a1 turned out to be the most advantageous solution. The factors that have a decisive impact on the ranking of variants and the selection of the best solution are the level of carbon dioxide emissions into the atmosphere and the total cost of the process for each variant. It is also worth pointing out that research based on multi-criteria decision support can be an effective tool to support the decision-maker in choosing the optimal technology for the transport of intermodal units and performing cargo operations.

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