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The influence of the scenario and assessment method on the choice of road alignment variants

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ABSTRACT

An efficient road network plays a key role in the economic development of almost any country. Road construction, apart from its many benefits, has also a negative impact on the natural environment causing its deterioration or division, introduces changes in area management, or may be the cause of social conflict. The decision to choose the most beneficial road alignment variant should take into account all of these aspects. It is therefore a multicriteria issue, based on transport, economic, social and environmental criteria. This article presents the influence of the assessment method of variants, criteria and their weights, as well as preference scenarios of road alignment with the example of the section of the S61 expressway, which is a part of the first Trans-European Transport Network (TEN-T). Four road alignment variants were analysed using the AHP, SAW and TOPSIS methods, with different sets of criteria weights and various preference scenarios. It has been shown, that the used variant assessment method, the criteria and their weights all have a significant influence on the results of the analysis and there is need for more uniform rules in reference to the methodology of conducting multicriteria analyses in designing road alignment.

1. Introduction

The problem of the construction of roads in each country is an important issue, since an efficient road network plays a crucial role in the economic development. The decision to choose the most beneficial road alignment variant should take into account the economic and transport criteria, as well as problems connected with the everyday lives of local communities and environment protection. This is why before commencing the designing work, an analysis of the road′s influence on the environment is conducted, and its best alignment in relation to the most precious local resources is determined (Geneletti, 2005). The choice of the optimal variant is a difficult and complicated task, and the multicriteria analysis is the most common method of facilitating the decision making process in a situation where there are many alternative choices to take into account. It is based on an appropriate choice of assessment criteria and importance values of mostly transport, environmental, economic and social criteria (De Silva and Tatam, 1996; Kalamaras et al., 2000; De Luca et al., 2012). Researchers also point towards a wider division of criteria (Vickerman, 2000; Abbas, 2003; Cundric et al., 2008). In the multicriteria analysis both the quantity and quality criteria can be taken into account (Yelda and Shrestha, 2003; Jakimavicus and Burinskiene, 2009; Haghighat, 2011).

There are many known methods for conducting multicriteria analyses. With the choice of the road alignment the methods of the French school based on the principle of exceeding are taken into account as well as the American school often called the methods of the monocriteria synthesis, introducing the normalization of the criteria which enables their mutual comparison. The most often used methods of the French school are the ELECTRE and PROMETHEE family methods: ELECTRE (Elimination et Choice Translating Reality) i PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations). However, there exists a wide group of less popular methods which are based on the main idea taken from the ELECTRE methods. The methods mentioned are ORESTE, QUALIFLEX, REGIME, ARGUS, MELCHIOR.

The ELECTRE method was used to choose the waste management system (Hokkanen and Salminen, 1997), and the PROMETHEE method to assess the investment projects (Nowak, 2005).

The American school methods are AHP (Analytic Hierarchy Process), SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), COPRAS (Complex Proportional Assessment), VIKOR (Tudela et al. (2006) used

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the AHP method as an alternative to the Cost-Benefit Analysis method (CBA) to improve a part of the road system in the Chiguayante district in Chile. The results obtained from the AHP and CBA methods varied significantly. It has been concluded, that the society should take part in the decision making process, which would allow to obtain precise and up to date information about the projects. Moreover, a number of variants needs to be considered in order to compare their influence on the natural environment and society.

The SAW method was used to assess transport network development scenarios for the city of Vilnius (Jakimavicus and Burinskiene, 2009). A comparative analysis of the SAW and COPRAS methods can be found in Podvezko (2011). In the SAW method, the values of the criteria are maximized, and minimising criteria should be converted to maximising. In the COPRAS method, the maximizing and minimizing criteria are dealt with separately.

The TOPSIS method was used to rank roads according to safety level (Haghighat, 2011). The road safety coefficient was determined based on various quantity and quality criteria. A comparative analysis of the TOPSIS and VIKOR methods is presented in the work by (Opricovic and Tzeng, 2004) and it shows that the methods use different ways of normalization of the criteria and introduce different aggregating functions. This, however, does not influence the end values of the variants.

Sayers et al. (2003) have confirmed the possibility of using a linear model, by calculating the weighted sum, for assessing transport projects and suggest using a flexible approach to determining criteria weights – setting limits for relative criterion weight values instead of trying to determine an exact value. This leads to a clear and flexible decision making process. The preferences, which led to the final result, will be clearly determined and available to the public opinion which will reduce the risk of random or one-sided decisions.

(Gallo et al., 2011; Cipriani et al., 2012) have used a heuristic procedure and a genetic algorithm in order to find the optimal bus networks with the assumption of a flexible demand. (Gao et al., 2004) has presented a two-level model of designing networks for the transport system using the heuristic algorithm.

While selecting the road alignment, the criteria chosen to assess the variants are usually grouped together as environmental, social, economic and transport. Each criterion is assigned an appropriate weight, accordingly to its significance. These weights modify the criteria values accordingly to the preferences of the governing body and may be determined with them or by experts. In a situation when the governing body alone determines the weights of the criteria, it has significant influence on the results of the analysis, and the chosen road alignment is to a large extent based on that body's preference. Introducing experts to this process is a much better solution, along with studying the degree of the assessment agreement correlation by using statistical tests, such as the Kendall's concordance test (Legendre, 2005). The measurement of the co-dependency is Kendall's W. The W coefficient can have a value from '0' (no concordance) to '1' (complete concordance). A high W coefficient value is interpreted as the agreement of experts in assessing the variants. One of the possible algorithms for solving the problem is the usage of a balanced approach – all criteria groups have the same weight (Freudensprung et al., 1995; Janic and Reggiani, 2002; Geneletti, 2005).

In order to assess the variants in a multicriteria analysis, the sensitivity analysis is also used, which allows to assess how the variant ranking changes when the weights of individual criteria change (Freudensprung et al., 1995; Kalamaras et al., 2000; Janic and Reggiani, 2002; Geneletti, 2005). Freudensprung et al. (1995) when determining the Brenner transport corridor in the Alps, have analysed six preference scenarios: indifferent, ecological I, ecological II, ecological – cost mix, democratic, network efficiency. Kalamaras et al. (2000) have used the variant sensitivity analysis to choose the motorway alignment with the following preference scenarios: minimising construction problems, minimising influence on the environment, maximising economic results, and maximising functionality. The chosen weights in the individual preference scenarios allowed them to choose the most beneficial motorway alignment variant. Janic and Reggiani (2002) have conducted a multicriteria analysis of the possible locations for an airport with these three preference scenarios: the first intended to equate the weights for all the criteria, the second one used weights with even distribution taken from a simulation, the third scenario used weight values determined by an entropy method. Geneletti (2005) in order to assess the variants of land corridors used three preference scenarios: neutral, ecological and socio-economic.

The presented review of the chosen topics in the multicriteria analysis subject point to a series of crucial problems in the decision making process. The aim of this article is to assess the influence of the chosen variant assessment method, the chosen criteria and their weights, and the used preference scenario on the choice of road alignment. The analysis was conducted using the AHP, SAW and TOSIS methods with the example of a section of the S61 expressway, which is a part of the first Trans-European Transport Network (TEN-T) Helsinki–Tallin–Riga–Kaunas–Warsaw.

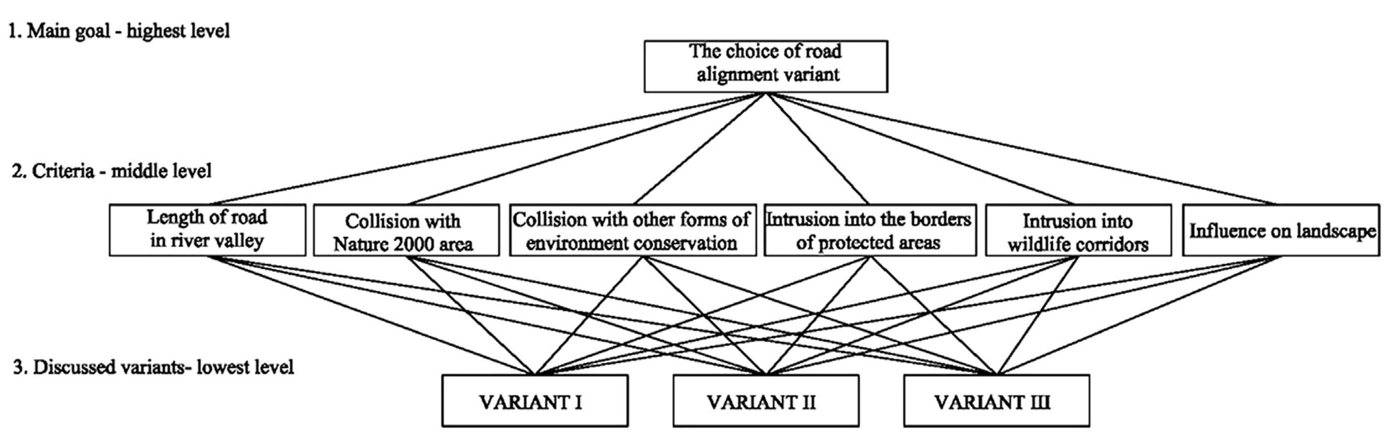

Fig. 1. Hierarchy structure for the choice of road alignment variant.

2. The general characteristic of the selected methods used for the choice of road alignment

The AHP, SAW and TOPSIS methods are often used in multi-criteria decision making problems, which also include transport issues (Janic and Reggiani, 2002; Tudela et al., 2006; Jakimavicus and Burinskiene, 2009; ZeinEldin, 2012). Each of these methods adapts different approaches to solving the multicriteria issue. Their short characteristic is presented below.

2.1. The AHP method (Analytic Hierarchy Process)

The AHP method was designed by an American mathematician (Saaty, 2003, 2004). It is one of the fastest developing and most known methods combining elements of mathematics and psychology. The first step in the AHP method is to organise a hierarchy of the decision-making process. At the highest level is the main goal, and at the lowest – the discussed variants. The middle levels are occupied by the analysed criteria. In Fig. 1 an example hierarchy model is presented for the choice of road alignment.

The next stage in the AHP method is to assess the elements in the individual levels of the hierarchy in pairwise comparison (each one with each one) utilizing a 9 element grading scale (Table 1) (Saaty, 2004).

As a result of assessment of elements found on each level, a comparison matrix is created, which general form is expressed by Eq. (1). The size of the matrix is equal to the number of compared elements.

$$\begin{bmatrix} a_{11}=1 & a_{12} & \cdots & a_{1n} \\ a_{21}=\dfrac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1}=\dfrac{1}{a_{1n}} & a_{n2}=\dfrac{1}{a_{2n}} & \cdots & a_{nn}=1 \end{bmatrix} \tag{1}$$

Having a matrix of pairwise comparisons, in order to create a variant ranking we need to calculate the eigenvector of the matrix. The eigenvector expresses the grades of the analysed criteria and variants with regards to the main goal. Next, the analysed elements are attributed according to the size of their calculated vectors in the order of their importance. The greater the vector value, the more significant the corresponding element. Saaty suggests four methods for calculating eigenvectors. The r_i vector was calculated by multiplication of $CI=\frac{\lambda_{\max}-n}{(n-1)}$elements in every row of the comparison matrix and deriving the root, which index equals the number of elements in the row. The obtained numbers are then normalized to units by dividing each one by their sum (Table 2). The obtained values are the W_i eigenvector of the comparison matrix (Merwe and Shand, 2008).

The eigenvectors of the pairwise comparison matrix after normalisation determine the importance of decisive elements at each level of the hierarchy. They are the local values of these elements.

During the next step, the normalisation of the analysed variants takes place in relation to each discussed criterion according to Merwe and Shand (2008):

$$N_{ij}=\frac{W_{ij}}{maximumW_{ij}} \tag{2}$$

where

N_{ij} – the eigenvector of the comparison matrix of i-th variant in relations to j-th criterion after normalisation,
W_{ij} – the eigenvector of the comparison matrix of i-th variant in relations to j-th criterion.

The final assessment of the analysed variants is obtained as a result of multiplication of the values at the local level and the level directly above.

The benefit of the AHP method is the possibility of checking the correctness of the obtained results by calculating the ‘Consistency Index’ (CI). Saaty suggested the following method of its calculation (Saaty, 2004):

$$CI=\frac{\lambda_{\max}-n}{(n-1)} \tag{3}$$

$\lambda_{\max}$ – maximum eigenvalue of the matrix,
n – size of the matrix.

An additional element to confirm data cohesion is the ‘Consistency Ratio’ (CR) calculated by (Saaty, 2004):

$$CR=\frac{CI}{RI} \tag{4}$$

where

RI – is a ‘Random Index’, which value depends on the number of n objects compared. The RI values are presented in Table 3.

It is assumed that when the values $CI \le 0.1$ and $CR \le 0.1$, then the cohesion of data entered into the comparison matrix is sufficient. In other case all or some comparisons are suggested to be repeated in order to eliminate incohesions in the pairwise comparisons.

Table 1
Scale of relative importances.
Source: Saaty (2004).

Intensity of importance		Definition
k	**1/k**	
1	1	Equal importance
3	1/3	Moderate importance
5	1/5	Strong importance
7	1/7	Very strong or demostrated importace
9	1/9	Extreme importance
2, 4, 6, 8	1/2, 1/4, 1/6, 1/8	To compare between mentioned values 1, 3, 5, 7, 9

Table 2
Calculating the eigenvector of the comparison matrix.

	A_1	A_2	A_3	r_i	W_i
A_1	1	a_{i1}	a_{i2}	$\sqrt[3]{1\cdot a_{i1}\cdot a_{i2}}$	$\frac{r_{i1}}{\sum ri}$
A_2	$\frac{1}{a_{i1}}$	1	a_{i3}	$\sqrt[3]{\frac{1}{a_{i1}}\cdot 1\cdot a_{i3}}$	$\frac{r_{i2}}{\sum ri}$
A_3	$\frac{1}{a_{i2}}$	$\frac{1}{a_{i3}}$	1	$\sqrt[3]{\frac{1}{a_{i2}}\cdot\frac{1}{a_{i3}}\cdot 1}$	$\frac{r_{i3}}{\sum ri}$
					$\sum W_i=1$

Table 3
Random index.
Source: Saaty (2004).

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

2.2. The SAW method (Simple Additive Weighting)

The SAW method, which bases on the criteria maximisation, is one of the oldest and most commonly used multicriteria methods. Minimizing criteria can be converted into maximizing ones by the formula (Podvezko, 2011):

$$x_{ij}^{*} = \frac{\min\limits_{j} x_{ij}}{x_{ij}} \tag{5}$$

where:

x_{ij}^{*} – the normalized value of i-th criterion for j-th alternative,
x_{ij} – the i-th criterion′s value for j-th alternative,
$\min\limits_{j} x_{ij}$ – the smallest i-th criterion′s value for all the alternatives compared.

The transformation formula used for maximizing criteria is as follows (Podvezko, 2011):

$$x_{ij}^{*} = \frac{x_{ij}}{\max\limits_{j} x_{ij}} \tag{6}$$

where

$\max\limits_{j} x_{ij}$ – the largest i-th criterion′s value all the alternatives compared.

The sum S_j of the weighted normalized values of all the criteria is calculated for the j-th alternative:

$$S_j = \sum_{i=1}^{m} \varpi_i \cdot x_{ij}^{*} \tag{7}$$

where

ϖ_i – is the i-th criterion weight for j-th alternative $\left(\sum_{i=1}^{m} \varpi_i = 1\right)$,
x_{ij}^{*} – the normalized value of i-th criterion for j-th alternative,
$i=1,\ldots,m$; $j=1,\ldots,n$; m is the number of criteria used and n is the number of the alternatives compared.

The alternatives of the largest value of criterion S_j is the best solution.

2.3. The TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution)

TOPSIS method was developed by Hwang and Yoon (1981) to solve multi-criteria decision problems. The method is based on the assumption that the optimal alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The TOPSIS procedure consist of the following steps (Opricovic and Tzeng, 2004; Haghighat, 2011):

a) Calculating the normalised decision matrix (criteria normalisation) according to the equation:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^{2}}} \tag{8}$$

b) Calculating the weighted normalized decision matrix:

$$v_{ij} = \varpi_i \cdot x_{ij}^{*} \quad i = 1, \ldots, m \quad j = 1, \ldots, n \tag{9}$$

where ϖ_i is the weight of each criterion, and $\sum_{i=1}^{m} \varpi_i = 1$.

c) Calculating the ideal A^* and negative ideal A^- solution. Depending on the type of criteria (benefit or cost) selected the best value is the maximum value for the benefit criterion and the minimum value for a cost criterion.

$$A^{*} = (v_1^{*}, v_2^{*}, \ldots, v_k^{*}) = \left\{ \left(\max_{i=1\ldots m} v_{ij} \middle| j \in J_Q\right), \ \left(\min_{i=1\ldots m} v_{ij} \middle| j \in J_C\right) \right\} \tag{10}$$

$$A^{-} = (v_1^{-}, v_2^{-}, \ldots, v_k^{-}) = \left\{ \left(\min_{i=1\ldots m} v_{ij} \middle| j \in J_Q\right), \left(\max_{i=1\ldots m} v_{ij} \middle| j \in J_C\right) \right\} \tag{11}$$

where J_Q is associated with benefit criteria and J_C is associated with cost criteria.

d) Calculating the separation measures, using n-dimensional Euclidean distance. The separation of each alternative from ideal solution is given as

$$d_i^{*} = \sqrt{\left(\sum_{j=1\ldots k} (v_{ij} - v_j^{*})^2 \right)} \tag{12}$$

$$d_i^{-} = \sqrt{\left(\sum_{j=1\ldots k} (v_{ij} - v_j^{-})^2 \right)} \tag{13}$$

e) Calculating the relative closeness to the ideal solution. The relative closeness is defined as

$$c_i^{*} = \frac{d_i^{-}}{d_i^{*} + d_i^{-}}, \quad c^{*} \in <0, 1> \tag{14}$$

f) The best solution is the shortest to d^* and the farthest distance from d^-.

Therefore, the object closest to ideal solution A^* and the most farthest distance from the negative ideal solution will have the most value (near the limit value) ratio c^*. An object that obtains the highest value of this ratio, it is considered the best in the study of decision problem.

3. The choice of road alignment variant – analysis of the influence of preference scenarios and variant assessment methods

3.1. Assumptions

The analysis of the influence of the method, criteria weight and preference scenarios on the choice of road alignment variants is presented with the example of a section of the S61 expressway which is a part of the Trans-European Transport Network (TEN-T) Helsinki–Tallinn–Riga–Kaunas–Warsaw (Fig. 2). In the territory of Poland it will be an important transit route, connecting the central part of the country with its north-eastern regions and of high economic significance to the local units within the vicinity of the planned corridor.

The variants of the alignment of the S61 road section used in the analysis are presented in Fig. 2:

- variant 1 – the bypass will run north of the town, the designed road intrudes into areas important to the environment (nature park), the length of the bypass is 8.195 km,
- variant 2 – the bypass will run north of the town, the designed road intrudes into areas important to the environment (nature park) as well as forest areas, the length of the bypass is 8.205 km,
- variant 3 – the bypass will run south of the town, the designed road is closest to built-up areas, the length of the bypass is 8.032 km,

Fig. 2. The first Trans-European Transport Network and the available variants.

- variant 4 – the bypass will run south of the town, the designed road intrudes the least into areas of environmental significance, the length of the bypass is 8.392 km.

Taking into account the characteristic of the area which the road would be in, the author selects the variants of similar length and significant differences in the intrusion level into environmentally protected areas (nature parks, ecological sites, ecological corridors).

The multicriteria analysis of the road section alignment was conducted basing on eleven sub-criteria (K1–K11) grouped as transport, environmental, economic and social criteria (Table 4). Special attention was paid to the environmental criteria due to the passing of the S61 expressway through the north-eastern regions of Poland which are uniquely diversified biologically (Nature 2000 areas, the Green Lungs of Poland, national parks – more than 30% are areas of unique environmental properties which are protected by law) and social criteria due to the frequent protests of local communities against road constructions, house demolishing and resettlement. The values of individual criteria were determined by the authors based on their own calculations and estimates. In order to better clarify the influence of the method of variant assessment, criteria and preference scenarios on the choice of road alignment, the number of sub-criteria was limited to eleven. The transport criteria take into account only the length and tortuosity of the road. The environmental criteria are collision of the designed variants with areas of protected landscape (nature parks), collision with ecological sites, intrusion into ecological corridors and the length of the road through forest areas. The economic criteria include the costs of building the road, and the number of engineering structures. The costs of road construction have been estimated based on the cost of one kilometer and determined as 6.5 million EUR in the case of a dual carriageway with two lanes in each direction. Social criteria include the number of residential buildings within 100 m from the road axis, the amount of residential buildings to be demolished and the number of plots for compulsory purchase. The analysis does not take into account environmental criteria related to vehicle traffic such as harmful emissions and noise pollution, soil pollution, probability of malfunction, tremors and vibrations.

Table 4
Description of road section alignment variants.

No.	Criteria	Variant			
		V1	V2	V3	V4
TRANSPORT					
K1	Road length [km]	8.195	8.205	8.032	8.392
K2	Road tortuosity [°/km]	10.49	13.28	13.19	15.01
ENVIRONMENTAL					
K3	Collision with nature parks [km]	4.230	4.165	2.972	2.797
K4	Collision with ecological sites [ha]	1.2	2.8	4.69	2.3
K5	Intrusion into wildlife corridors [km]	1.9	2.3	1.8	1.2
K6	Length of road in forest areas [km]	0.40	1.92	1.16	0.25
ECONOMIC					
K7	Construction costs [10^6 EUR]	53.267	53.332	52.208	54.548
K8	Number of engineering structures [number]	7	6	6	8
SOCIAL					
K9	Number of residential buildings within 100 m from road axis [number]	16	7	15	12
K10	Number of buildings to be demolished [number]	9	4	9	8
K11	Number of plots for compulsory purchase [number]	98	106	127	120

3.2. *The influence of method and criteria weights on variant assessment*

The influence of the method of variant assessment on the choice of the alignment of the section of the S61 expressway with different weights of individual criteria (environmental, transport, economic, social) is presented below. The first stage assumes criteria weights determined according to pair comparison used in the AHP method. Taking into account the information in (ZeinEldin, 2012) similar criteria weights have been chosen for the SAW and TOPSIS method analyses. The next steps analyse the influence of the variant assessment method with a balanced approach (identical criteria weights) and with the assumption of the environment–social criterion as the beneficial one.

The decision regarding the chosen criteria weights took into account the fact that the main goal of the article is to present the influence of the method and scenarios on the choice of the optimal road alignment. The weight values used in the analyses were determined by the authors basing on data found in literature and on the weight values used in other papers similar in character (Freudensprung et al., 1995; Kalamaras et al., 2000; Janic and Reggiani, 2002; Geneletti, 2005). A detailed presentation of the results of calculations using the AHP method can be found below. As for the calculations for the remaining two methods, only the end results are presented.

The results of the calculations using the AHP method, have been presented in detail, whereas in the case of the two remaining methods, only the final results of the conducted calculations have been presented.

3.2.1. The environmental criterion as the decidedly preferable scenario

3.2.1.1. The AHP method. Due to the passage of the S61 expressway through areas of unique biological diversity (Nature 2000 areas, the Green Lungs of Poland, national parks) the highest significance was given to the environmental criteria. The criteria K3–K6 have been assigned 7 points each, with the less significant criteria being K1, K2, K9, K11.

Table 5 presents the results of the conducted quantitative analysis of the significance of individual criteria, and Table 6 shows a comparison of all analysed variants in relation to every adapted criterion.

The results of the calculations given in Tables 5 and 6 served as the base for creating a ranking of variants (Table 7).

The analysis conducted with the AHP method points to variant 4 as the best one and variant 2 as the worst.

The correctness of the comparison matrix values was checked by calculating the consistency index and consistency ratio. The values of the consistency index *CI* and the consistency ratio *CR* for individual matrixes were in the range from 0.02 to 0.10. This means that the described analysis was conducted correctly.

3.2.1.2. The SAW method. According to the aims of the SAW method, the Eq. (5) was used to normalise the minimising criteria, and the results of the calculation are presented in Table 8. The weights of the criteria have been taken from the AHP method (Table 5). Table 9 shows the results of the analysis according to the SAW method, where the best result is variant 4, and the worst – variant 2.

3.2.1.3. The TOPSIS method. Criteria weights are the same as in the AHP method (Table 5). The normalization of the criteria has been conducted with the use of the Eq. (8) (Table 10). Table 11 shows the determined ideal vectors A^* and the negatively ideal A^-.

Table 12 shows the determined vectors of the Euclidean length, and Table 13 shows the variant ranking. According to the TOPSIS method, the best variant of road section alignment is variant 4, and the worst – variant 3.

Table 14 shows the results of calculations conducted with the use of the three methods of variant assessment, with criteria weights according to the AHP method. According to each method, the best road alignment variant for the section of the S61 expressway was variant 4, characterised by the smallest intrusion factor into protected areas and ecological corridors, as well as passing through forest areas on a shortest distance. The presented results confirm that with a decisive advantage of one criterion (the weight of the environmental criterion is 71%) the chosen method for variant assessment is practically of no influence in the decision making process of choosing the best variant.

3.2.2. The balanced approach (identical weight values of criteria)

The balanced approach assumes equal weight values (0.25) in relations to the four main criteria (transport, environmental, economic, social). A proportional division of the weight values into additional criteria was conducted within each of the main criteria (Table 15). Such assumption was possible only due to the theoretical character of the presented example. In relation to a real case scenario the weight of each criterion should be established individually. The results of the analysis of the S61 expressway alignment variants according to the AHP, SAW and TOPSIS methods are shown below.

In the AHP method the criteria weights obtained through the transformation of the salience matrix were replaced with the criteria values shown in Table 15. The results of the calculations and the variant ranking are shown in Table 16.

The conducted variant analysis using the identical weights approach shows that the choice of the variant is influenced in a large extent by the selected assessment method. The identical weights approach shows a change in the variant ranking in comparison to the analysis using criteria weights from the AHP method. The best variant according to the AHP method is variant 3, according to the SAW method – variant 2, whereas according to the TOPSIS method – variant 4.

3.2.3. The environmental–social approach

The environmental–social approach assumes the following weights: environmental criterion – 0.35, social criterion – 0.35, transport criterion – 0.15 and economic criterion – 0.15 (Table 17). The social and environmental criteria weights established in such a manner show that while choosing the road alignment variant

Table 5
Determining the significance of the criteria.

Criteria	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	r_i	W_i
K1	**1**	5	1/7	1/7	1/7	1/7	1	1/3	3	1/3	3	0.5705	0.0358
K2	1/5	**1**	1/7	1/7	1/7	1/7	1/5	1/3	3	1/5	3	0.3511	0.0221
K3	7	7	**1**	1	3	3	5	5	5	3	5	3.4510	0.2169
K4	7	7	1	**1**	3	3	5	5	5	3	5	3.4510	0.2169
K5	7	7	1/3	1/3	**1**	1	5	5	5	3	5	2.3145	0.1455
K6	7	7	1/3	1/3	1	**1**	3	5	5	2	5	2.1295	0.1338
K7	1	5	1/5	1/5	1/5	1/3	**1**	3	5	3	5	1.1050	0.0695
K8	3	3	1/5	1/5	1/5	1/5	1/3	**1**	5	1/3	5	0.7463	0.0469
K9	1/3	1/3	1/5	1/5	1/5	1/5	1/5	1/5	**1**	1/5	1/7	0.2464	0.0155
K10	3	5	1/3	1/3	1/3	1/2	1/3	3	5	**1**	5	1.1926	0.0750
K11	1/3	1/3	1/5	1/5	1/5	1/5	1/5	1/5	7	1/5	**1**	0.3510	0.0221
											$\sum$	**15.9089**	**1.00**

Table 6
Comparison of variants in relations to all criteria.

	V1	V2	V3	V4	r_{i1}	W_{i1}	N_{i1}
K1 – road length							
V1	**1**	1	1/3	3	1.00	0.201	0.39
V2	1	**1**	1/3	3	1.00	0.201	0.39
V3	3	3	**1**	5	2.59	0.520	1.00
V4	1/3	1/3	1/5	**1**	0.39	0.078	0.15
				∑	**4.98**	**1.000**	
K2 – road tortuosity							
V1	**1**	3	3	5	2.59	0.520	1.00
V2	1/3	**1**	1	3	1.00	0.201	0.39
V3	1/3	1	**1**	3	1.00	0.201	0.39
V4	1/5	1/3	1/3	**1**	0.39	0.078	0.15
				∑	**4.98**	**1.000**	
K3 – collision with nature parks							
V1	**1**	1	1/3	1/5	0.51	0.096	0.17
V2	1	**1**	1/3	1/5	0.51	0.096	0.17
V3	3	3	**1**	1/3	1.32	0.249	0.45
V4	5	5	3	**1**	2.94	0.558	1.00
				∑	**5.28**	**1.000**	
K4 – collision with ecological sites							
V1	**1**	5	9	3	3.41	0.576	1.00
V2	1/5	**1**	5	1/3	0.76	0.128	0.22
V3	1/9	1/5	**1**	1/5	0.26	0.044	0.08
V4	1/3	3	5	**1**	1.50	0.253	0.44
				∑	**5.92**	**1.000**	
K5 – intrusion into ecological corridors							
V1	**1**	3	1	1/5	0.88	0.169	0.30
V2	1/3	**1**	1/3	1/5	0.39	0.074	0.13
V3	1	3	**1**	1/3	1.00	0.192	0.34
V4	5	5	3	**1**	2.94	0.565	1.00
				∑	**5.21**	**1.000**	
K6 – length of road through forest areas							
V1	**1**	5	3	1/3	1.50	0.263	0.47
V2	1/5	**1**	1/3	1/7	0.31	0.055	0.10
V3	1/3	3	**1**	1/5	0.67	0.118	0.21
V4	3	7	5	**1**	3.20	0.564	1.00
				∑	**5.68**	**1.000**	
K7 – construction costs							
V1	**1**	1	1/3	3	1.00	0.201	0.39
V2	1	**1**	1/3	3	1.00	0.201	0.39
V3	3	3	**1**	5	2.59	0.520	1.00
V4	1/3	1/3	1/5	**1**	0.39	0.078	0.15
				∑	**4.98**	**1.000**	
K8 – number of engineering structures							
V1	**1**	1/3	1/3	3	0.76	0.151	0.39
V2	3	**1**	1	5	1.97	0.391	1.00
V3	3	1	**1**	5	1.97	0.391	1.00
V4	1/3	1/5	1/5	**1**	0.34	0.067	0.17
				∑	**5.04**	**1.000**	
K9 – number of residential buildings within 100 m from the road axis							
V1	**1**	1/5	1	1/3	0.51	0.096	0.17
V2	5	**1**	5	3	2.94	0.558	1.00
V3	1	1/5	**1**	1/3	0.51	0.096	0.17
V4	3	1/3	3	1	1.32	0.249	0.45
				∑	**5.28**	**1.000**	
K10 – number of residential buildings to be demolished							
V1	**1**	1/5	1	1/3	0.51	0.096	0.17
V2	5	**1**	5	3	2.94	0.558	1.00
V3	1	1/5	**1**	1/3	0.51	0.096	0.17
V4	3	1/3	3	**1**	1.32	0.249	0.45
				∑	**5.28**	**1.000**	
K11 – social conflict							
V1	**1**	3	5	5	2.94	0.540	1.00
V2	1/3	**1**	5	3	1.50	0.275	0.51
V3	1/5	1/5	**1**	1/3	0.34	0.062	0.12
V4	1/5	1/3	3	**1**	0.67	0.123	0.23
				∑	**5.45**	**1.000**	

special attention needs to be paid to environment protection and adhering to the voice of the local community. In the calculations using the AHP method, the criteria weights obtained through transforming the salience matrix were replaced with values presented in Table 17. The results of the calculations and the variant ranking are shown in Table 18.

Table 7
Ranking of variants according to the AHP method.

	Variant			
	V1	**V2**	**V3**	**V4**
Value	0.2619	0.1727	0.2022	0.3631
Rank	**2**	**4**	**3**	**1**

The conducted variant analysis using the environmental–social approach shows that the choice of the variant is influenced in a large extent by the selected assessment method. The environmental–social approach shows a change in the variant ranking in comparison to the analysis using criteria weights from the AHP method. The best variant according to the AHP method is variant 2, according to the SAW and TOPSIS methods – variant 4.

The calculations conducted according to the three suggested scenarios of determining criteria weights (environmental criterion as the decidedly preferable scenario, equal weights approach, environmental–social approach) did not result in an unambiguous answer as to the choice of the most beneficial road alignment for the designed road section. The variant ranking results are influenced by the calculation method, criteria normalisation method as well as the chosen criteria and their weights. The influence of the criteria weights is especially visible in the environmental approach. A significant advantage of the environmental criteria allowed to univocally determine the most beneficial variant regardless the method of calculations. The use of the identical weights approach led to a complete change in the variant rankings in comparison to the environmental approach (criteria weights adapter from the AHP method). When comparing the algorithms of the analysed methods it can be stated that the method of criteria normalization plays a crucial role in variant assessment. The SAW method uses linear normalization to normalize criteria, whereas the TOPSIS and AHP methods use vector normalisation. As a result of criteria normalization according to the SAW method we obtain significant differences between criteria values (Table 8) contrary to the TOPSIS method (Table 10) e.g. the length of the road through forest areas in variant V4 – value 1.0, whereas variant V2 – value 0.1302. In the AHP method the variant ranking also depends on the used comparison scale.

The approach with a preference set of environmental–social criteria also confirmed the influence of the selected method of calculations on the variant ranking. However, in this case the same solution was obtained for the SAW and TOPSIS methods.

The analysis presented above leads to the conclusion that the variant ranking is to a large extent influenced by the assumed criteria weights and the calculation method. A less significant role is played by the method of criteria normalization and the differences in the values of the analysed criteria. In order to explain the influence of criteria weights on the variant ranking, a sensitivity analysis was conducted.

3.3. Influence of the preference scenarios

The results of the analysis of variant sensitivity to changes in criteria weights is presented below. A choice of the optimal variant of road alignment was made for four preference scenarios: transport, environmental, economic and social, with a changing set of weights within the range of 10–90%. The preference scenario for the transport criterion ‘10/90’ means that the transport criteria group receives the weight of 10%, and the three remaining groups of criteria the weight of 90% (30% to each group of criteria:

Table 8
Normalization of criteria according to the method SAW.

No.	Criteria	Weights	Variant			
			1	2	3	4
K1	Road length [km]	0.0358	0.9801	0.9789	1.0000	0.9571
K2	Road tortuosity [°/km]	0.0221	1.0000	0.7899	0.7953	0.6989
K3	Collision with nature parks [km]	0.2169	0.6612	0.6715	0.9411	1.0000
K4	Collision with ecological sites [ha]	0.2169	1.0000	0.4286	0.2559	0.5217
K5	Intrusion into ecological corridors [km]	0.1455	0.6316	0.5217	0.6667	1.0000
K6	Length of road through forest areas [km]	0.1338	0.6250	0.1302	0.2155	1.0000
K7	Construction costs [10^6 EUR]	0.0695	0.9801	0.9789	1.0000	0.9571
K8	Number of engineering structures [number]	0.0469	0.8571	1.0000	1.0000	0.7500
K9	Number of residential buildings within a 100 m from the road axis [number]	0.0155	0.4375	1.0000	0.4667	0.5833
K10	Number of residential buildings to be demolished [number]	0.0750	0.4444	1.0000	0.4444	0.5000
K11	Number of plots for compulsory purchase [number]	0.0221	1.0000	0.9245	0.7717	0.8167

Table 9
Results of analysis with the SAW method.

	Variant			
	V1	V2	V3	V4
Value	0.2715	0.2170	0.2179	0.2935
Rank	**2**	**4**	**3**	**1**

environmental, economic and social), scenario '90/10' means that the transport criteria group receives the weight of 90%, and the three remaining groups of criteria the weight of 10% (3.33% to each group of criteria: environmental, economic and social). Sub-criteria have an even share within individual criteria groups. The sensitivity analysis for the AHP method with different weight sets is presented in Table 19, for the SAW method – in Table 20, and for the TOPSIS method – in Table 21. In Tables 19–21 the values referring to the optima variants within individual preference scenarios have been highlighted. Table 22 shows a cumulative breakdown of results for the analysed preference scenarios.

The analysis of variant sensitivity conducted using the AHP method shows that according to the transport and economic scenarios with the weight range from 30% to 90% the most beneficial is variant V3 (the shortest, lowest cost and lowest number of objects). In the case of the environmental scenario variant 4 (smallest intrusion into natural environment) is the most beneficial within the weight range from 40% to 90%, whereas in the case of the social scenario variant V2 (lowest number of buildings affected by noise and needed to be demolished) within the range from 30% to 90%.

The analysis of variants' sensitivity conducted using the SAW method shows that according to the transport scenario within the weight range from 30% to 90% the most beneficial solution is variant V1. In the case of the environmental scenario, variant V4 is the most beneficial within the weight range from 60% to 90%, whereas in the case of the economic and social scenarios variant V2 is the most beneficial within the weight ranges from 20% to 90% and from 30% to 90%, respectively.

Table 11
Ideal vector A^* and negative ideal vector A^-.

No.	Criteria	A^*	A^-
K1	Road length [km]	0.0175	0.0183
K2	Road tortuosity [°/km]	0.0088	0.0127
K3	Collision with nature parks [km]	0.0842	0.1274
K4	Collision with ecological sites [ha]	0.0430	0.1682
K5	Intrusion into ecological corridors [km]	0.0474	0.0908
K6	Length of road through forest areas [km]	0.0146	0.1121
K7	Construction costs [10^6 EUR]	0.0340	0.0355
K8	Number of engineering structures [number]	0.0207	0.0276
K9	Number of residential buildings within a 100 m from the road axis [number]	0.0042	0.0095
K10	Number of residential buildings to be demolished [number]	0.0193	0.0434
K11	Number of plots for compulsory purchase [number]	0.0095	0.0124

Table 12
Vectors d^* and d^- of the Euclidean distance.

	Variant			
	V1	V2	V3	V4
d^*	0.0577	0.1280	0.1404	0.0448
d^-	0.1544	0.0726	0.0620	0.1437

Table 10
Normalization of criteria according to the method TOPSIS.

No.	Criteria	Weights	Variant			
			V1	V2	V3	V4
K1	Road length [km]	0.0358	0.0179	0.0179	0.0175	0.0183
K2	Road tortuosity [°/km]	0.0221	0.0088	0.0112	0.0111	0.0127
K3	Collision with nature parks [km]	0.2169	0.1274	0.1254	0.0895	0.0842
K4	Collision with ecological sites [ha]	0.2169	0.0430	0.1004	0.1682	0.0825
K5	Intrusion into ecological corridors [km]	0.1455	0.0750	0.0908	0.0711	0.0474
K6	Length of road through forest areas [km]	0.1338	0.0234	0.1121	0.0677	0.0146
K7	Construction costs [10^6 EUR]	0.0695	0.0347	0.0347	0.0340	0.0355
K8	Number of engineering structures [number]	0.0469	0.0241	0.0207	0.0207	0.0276
K9	Number of residential buildings within a 100 m from the road axis [number]	0.0155	0.0095	0.0042	0.0089	0.0072
K10	Number of residential buildings to be demolished [number]	0.0750	0.0434	0.0193	0.0434	0.0386
K11	Number of plots for compulsory purchase [number]	0.0221	0.0095	0.0103	0.0124	0.0117

Table 13
Results of analysis with the TOPSIS method.

	Variant			
	V1	V2	V3	V4
Value	0.3373	0.1676	0.1420	0.3531
Rank	**2**	**3**	**4**	**1**

Table 14
Variant ranking by methods used.

Method	Results	Variant			
		V1	V2	V3	V4
AHP	Value	0.2619	0.1727	0.2022	0.3631
	Rank	**2**	**4**	**3**	**1**
SAW	Value	0.2715	0.2170	0.2179	0.2935
	Rank	**2**	**4**	**3**	**1**
TOPSIS	Value	0.3373	0.1676	0.1420	0.3531
	Rank	**2**	**3**	**4**	**1**

Table 15
Weight value distribution according to the identical weights approach.

No.	Criteria	Weights
TRANSPORT 0.25		
K1	Road length [km]	1/8
K2	Road tortuosity [°/km]	1/8
ENVIRONMENTAL 0.25		
K3	Collision with nature parks [km]	1/16
K4	Collision with ecological sites [ha]	1/16
K5	Intrusion into ecological corridors [km]	1/16
K6	Length of road through forest areas [km]	1/16
ECONOMIC 0.25		
K7	Construction costs [10^6 EUR]	1/8
K8	Number of engineering structures [number]	1/8
SOCIAL 0.25		
K9	Number of residential buildings within a 100 m from the road axis [number]	1/12
K10	Number of residential buildings to be demolished [number]	1/12
K11	Number of plots for compulsory purchase [number]	1/12

Table 16
Variant ranking according to the methods used – identical weights approach.

Method	Results	Variant			
		V1	V2	V3	V4
AHP	Value	0.2599	0.2675	0.2731	0.1994
	Rank	**3**	**2**	**1**	**4**
SAW	Value	0.2566	0.2583	0.2340	0.2511
	Rank	**2**	**1**	**4**	**3**
TOPSIS	Value	0.2925	0.2375	0.1760	0.2939
	Rank	**2**	**3**	**4**	**1**

The analysis of variants′ sensitivity conducted using the TOPSIS method shows that according to the transport scenario within the weight range from 30% to 90% the most beneficial solution is variant V1. In the case of the environmental scenario variant V4 is the most beneficial within the range from 30% to 90%, whereas in the case of the economic and social scenarios variant V2 is most beneficial within the weight ranges from 50% to 80% and from 40% to 90%, respectively.

The analysis of the above data points to a dependency of the variant ranking on the selected preference scenario (weight values assigned to individual criteria) and the calculation method. In the transport scenario variants V1 and V3 are dominant, in the environmental scenario variant V4, in the economic scenario variants V2 and V3, and in the social scenario variant V2. The influence of the difference in the values of individual criteria within the individual variants (for the dimension values) on the results of calculations needs to be noted. This problem was not, however, the subject of a more detailed analysis in this article.

Table 17
Weight value distribution according to the environmental–social approach.

No.	Criteria	Weights
TRANSPORT 0.15		
K1	Road length [km]	3/40
K2	Road tortuosity [°/km]	3/40
ENVIRONMENTAL 0.35		
K3	Collision with nature parks [km]	7/80
K4	Collision with ecological sites [ha]	7/80
K5	Intrusion into ecological corridors [km]	7/80
K6	Length of road through forest areas [km]	7/80
ECONOMIC 0.15		
K7	Construction costs [10^6 EUR]	3/40
K8	Number of engineering structures [number]	3/40
SOCIAL 0.35		
K9	Number of residential buildings within a 100 m from the road axis [number]	7/60
K10	Number of residential buildings to be demolished [number]	7/60
K11	Number of plots for compulsory purchase [number]	7/60

Table 18
Variant ranking according to the method used – the environmental–social approach.

Method	Results	Variant			
		V1	V2	V3	V4
AHP	Value	0.2602	0.2712	0.2139	0.2547
	Rank	**2**	**1**	**4**	**3**
SAW	Value	0.2553	0.2601	0.2223	0.2623
	Rank	**3**	**2**	**4**	**1**
TOPSIS	Value	0.2877	0.2320	0.1563	0.3241
	Rank	**2**	**3**	**4**	**1**

It has been determined, that the highest agreement of results was obtained in the case of the SAW method, in reference to the results obtained using the two other methods. The variant ranking is the most unstable for the economic scenario and the TOPSIS calculation method.

4. Conclusion

The choice of the most beneficial road alignment variant is a complex decision process, based on a multicriteria approach. The frequently used multicriteria methods in transport issues are AHP, SAW and TOPSIS methods.

For example, the AHP method was used in an assessment of a transport project connected with improving the road network in the Chiguayante district in Chile, the SAW method was used to assess development scenarios of the Vilnius transport system, and the TOPSIS method was used to rank roads in relations to their safety. There are also known examples of using heuristic methods in multicriteria assessment of road alignment variants.

In the AHP method the criteria weights are established by comparison in pairs.

The AHP method enables to determine the weights of criteria based on pair comparison and presenting the decision making process according to a hierarchic structure. The advantage of this method is the possibility of verifying the obtained results of the comparison matrix by calculating the non-concordance and

Table 19
Variant ranking according to preference scenarios – the AHP method.

Variant	Preference scenarios [%]								
	10/90	**20/80**	**30/70**	**40/60**	**50/50**	**60/40**	**70/30**	**80/20**	**90/10**
According to transport criteria									
V1	0.2400	0.2533	0.2666	0.2800	0.2934	0.3068	0.3202	0.3337	0.3472
V2	**0.2808**	**0.2720**	0.2631	0.2543	0.2455	0.2366	0.2277	0.2188	0.2099
V3	0.2558	0.2673	**0.2789**	**0.2906**	**0.3022**	**0.3139**	**0.3255**	**0.3372**	**0.3490**
V4	0.2235	0.2235	0.1913	0.1752	0.1590	0.1428	0.1265	0.1102	0.0939
Optimal	V2	V2	V3	V3	V3	V3	V3	V3	V3
According to environmental criteria									
V1	0.2574	0.2591	0.2608	**0.2626**	0.2644	0.2662	0.2681	0.2701	0.2721
V2	**0.2998**	0.2784	0.2566	0.2342	0.2113	0.1879	0.1639	0.1393	0.1141
V3	0.2950	**0.2805**	**0.2657**	0.2505	0.2350	0.2191	0.2028	0.1861	0.1690
V4	0.1479	0.1479	0.2169	0.2527	**0.2893**	**0.3268**	**0.3652**	**0.4045**	**0.4448**
Optimal	V2	V3	V3	V1	V4	V4	V4	V4	V4
According to economic criteria									
V1	**0.2809**	**0.2668**	0.2532	0.2403	0.2278	0.2159	0.2044	0.1933	0.1826
V2	0.2575	0.2643	0.2707	0.2769	0.2829	0.2886	0.2941	0.2994	0.3045
V3	0.2317	0.2596	**0.2864**	**0.3120**	**0.3367**	**0.3603**	**0.3831**	**0.4050**	**0.4261**
V4	0.2299	0.2299	0.1896	0.1708	0.1526	0.1352	0.1184	0.1023	0.0868
Optimal	V1	V1	V3	V3	V3	V3	V3	V3	V3
According to social criteria									
V1	0.2622	0.2607	0.2592	0.2576	0.2560	0.2543	0.2527	0.2510	0.2492
V2	0.2317	0.2555	**0.2797**	**0.3043**	**0.3294**	**0.3548**	**0.3808**	**0.4072**	**0.4340**
V3	**0.3080**	**0.2848**	0.2613	0.2374	0.2131	0.1883	0.1631	0.1375	0.1114
V4	0.1981	0.1981	0.1998	0.2007	0.2016	0.2025	0.2034	0.2044	0.2054
Optimal	V3	V3	V2	V2	V2	V2	V2	V2	V2

Table 20
Variant ranking according to preference scenarios – the SAW method.

Variant	Preference scenarios [%]								
	10/90	**20/80**	**30/70**	**40/60**	**50/50**	**60/40**	**70/30**	**80/20**	**90/10**
According to transport criteria									
V1	0.2523	0.2552	**0.2580**	**0.2607**	**0.2633**	**0.2658**	**0.2682**	**0.2705**	**0.2728**
V2	**0.2612**	**0.2592**	0.2573	0.2555	0.2537	0.2520	0.2503	0.2487	0.2472
V3	0.2305	0.2329	0.2352	0.2374	0.2396	0.2417	0.2437	0.2456	0.2475
V4	0.2560	0.2560	0.2495	0.2464	0.2435	0.2406	0.2378	0.2351	0.2325
Optimal	V2	V2	V1	V1	V1	V1	V1	V1	V1
According to environmental criteria									
V1	0.2523	0.2551	**0.2581**	0.2612	**0.2633**	0.2680	0.2717	0.2756	0.2797
V2	**0.2719**	**0.2629**	0.2535	0.2436	0.2537	0.2220	0.2103	0.1978	0.1846
V3	0.2390	0.2357	0.2323	0.2287	0.2396	0.2210	0.2167	0.2123	0.2075
V4	0.2368	0.2368	0.2561	**0.2665**	0.2435	**0.2891**	**0.3014**	**0.3144**	**0.3282**
Optimal	V2	V2	V1	V4	V1	V4	V4	V4	V4
According to economic criteria									
V1	**0.2596**	0.2576	0.2556	0.2538	0.2520	0.2503	0.2487	0.2471	0.2291
V2	0.2571	**0.2579**	**0.2586**	**0.2594**	**0.2600**	**0.2607**	**0.2613**	**0.2619**	**0.3351**
V3	0.2262	0.2315	0.2365	0.2413	0.2459	0.2502	0.2544	0.2584	0.2056
V4	0.2570	0.2570	0.2492	0.2456	0.2421	0.2388	0.2356	0.2326	0.2301
Optimal	V1	V2	V2	V2	V2	V2	V2	V2	V2
According to social criteria									
V1	**0.2621**	**0.2585**	0.2547	0.2538	0.2467	0.2426	0.2382	0.2338	0.2291
V2	0.2428	0.2530	**0.2636**	**0.2594**	**0.2859**	**0.2975**	**0.3096**	**0.3222**	**0.3351**
V3	0.2398	0.2360	0.2321	0.2413	0.2238	0.2195	0.2150	0.2104	0.2056
V4	0.2553	0.2553	0.2496	0.2456	0.2436	0.2404	0.2371	0.2337	0.2301
Optimal	V1	V1	V2	V2	V2	V2	V2	V2	V2

concordance coefficients. In the SAW method, the analyses are simple and transparent, and the TOPSIS method is used due to its logical way of sorting the alternatives with regard to their similarity to the most preferable variant. The similarity in the TOPSIS method is determined on the basis of minimizing the distance to the most desirable variant and maximising the distance to the least desirable variant. In both methods the problem is the difficulty in setting the weights of individual criteria. This problem does not exist in the case of the AHP method, where criteria weights are determined based on a comparison matrix.

The conducted calculations have shown that each of the mentioned methods (AHP, SAW, TOPSIS) may be used in the choice of the most beneficial variant of road alignment. It was determined that the highest agreement of results was obtained in the case of the SAW method, in relations to the results obtained using the two other methods.

This means that the SAW method may be used as a reference method in comparing the results obtained using other methods. In the analyses presented in this article the solutions obtained for the SAW and TOPSIS methods are more similar than the ones obtained for the SAW and AHP methods. An important role in selecting the

Table 21
Variant ranking according to preference scenarios – the TOPSIS method.

Variant	Preference scenarios [%]								
	10/90	20/80	30/70	40/60	50/50	60/40	70/30	80/20	90/10
According to transport criteria									
V1	0.2826	0.2878	**0.2989**	**0.3175**	**0.3444**	**0.3792**	**0.4198**	**0.4634**	**0.5065**
V2	0.2370	0.2374	0.2376	0.2369	0.2340	0.2286	0.2218	0.2164	0.2150
V3	0.1726	0.1744	0.1781	0.1842	0.1926	0.2027	0.2129	0.2217	0.2287
V4	**0.3078**	**0.3078**	0.2853	0.2614	0.2289	0.1896	0.1455	0.0986	0.0499
Optimal	V4	V4	V1	V1	V1	V1	V1	V1	V1
According to environmental criteria									
V1	0.2405	**0.2767**	0.3054	0.3231	0.3329	0.3380	0.3405	0.3416	0.3421
V2	**0.3682**	0.2735	0.2091	0.1698	0.1467	0.1337	0.1266	0.1231	0.1216
V3	0.1881	0.1796	0.1730	0.1683	0.1652	0.1631	0.1619	0.1613	0.1610
V4	0.2033	0.2033	**0.3126**	**0.3388**	**0.3552**	**0.3652**	**0.3710**	**0.3740**	**0.3754**
Optimal	V2	V1	V4	V4	V4	V4	V4	V4	V4
According to economic criteria									
V1	0.2980	0.2950	**0.2893**	**0.2805**	0.2689	0.2546	0.2388	0.2236	0.2115
V2	0.2325	0.2351	0.2411	0.2521	**0.2692**	**0.2920**	**0.3186**	**0.3461**	0.3708
V3	0.1592	0.1684	0.1857	0.2104	0.2405	0.2736	0.3078	0.3415	**0.3742**
V4	**0.3103**	**0.3103**	0.2840	0.2570	0.2214	0.1798	0.1348	0.0888	0.0435
Optimal	V4	V4	V1	V1	V2	V2	V2	V2	V3
According to social criteria									
V1	**0.3383**	**0.3093**	0.2756	0.2429	0.2124	0.1853	0.1633	0.1479	0.1393
V2	0.1711	0.2105	0.2679	**0.3348**	**0.4042**	**0.4697**	**0.5253**	**0.5664**	**0.5907**
V3	0.1892	0.1823	0.1679	0.1478	0.1248	0.1012	0.0797	0.0627	0.0524
V4	0.3014	0.3014	**0.2885**	0.2745	0.2587	0.2437	0.2317	0.2230	0.2176
Optimal	V1	V1	V4	V2	V2	V2	V2	V2	V2

Table 22
A cumulative breakdown of results for the analysed preference scenarios.

Criteria	Method	10/90	20/80	30/70	40/60	50/50	60/40	70/30	80/20	90/10
TRANS	AHP	V2	V2	V3	V3	V3	V3	V3	V3	V3
	SAW	V2	V2	V1	V1	V1	V1	V1	V1	V1
	TOPSIS	V4	V4	V1	V1	V1	V1	V1	V1	V1
ENVIR	AHP	V2	V3	V3	V1	V4	V4	V4	V4	V4
	SAW	V2	V2	V1	V4	V1	V4	V4	V4	V4
	TOPSIS	V2	V1	V4	V4	V4	V4	V4	V4	V4
ECON	AHP	V1	V1	V3	V3	V3	V3	V3	V3	V3
	SAW	V1	V2	V2	V2	V2	V2	V2	V2	V2
	TOPSIS	V4	V4	V1	V1	V2	V2	V2	V2	V3
SOCIAL	AHP	V3	V3	V2	V2	V2	V2	V2	V2	V2
	SAW	V1	V1	V2	V2	V2	V2	V2	V2	V2
	TOPSIS	V1	V1	V4	V2	V2	V2	V2	V2	V2

most beneficial variant is played by the method of normalization of the criteria. In the SAW method linear normalization is used, whereas the TOPSIS and AHP methods both use vector normalization.

The conducted analyses, assuming the environmental criterion as the most beneficial (the weight of the environmental criterion was 71%), have confirmed, that the method of variant assessment has practically no influence on the choice of the road alignment variant. In a balanced approach (equal weights of criteria) and with two criteria being decisively advantageous (e.g. weights of two criteria are greater than 30% each) the method of variant assessment has influence on the result of the analysis.

With the results of calculations and analyses in mind, it needs to be stated that in choosing the most beneficial road alignment variant, with a decisive advantage of one of the criteria (greater than 70%) any of the three analysed methods may be used. In case of similar weight values or with an advantage of one or two criteria (around 30–40% each), it is advisable to use the AHP method, with the SAW method being the reference method. The choice of the AHP method as the basic method is supported by the fact that it allows for a relatively easy determination of the weights of the chosen criteria.

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