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MULTI-CRITERIA DECISION-MAKING WHEN CHOOSING VARIANT SOLUTION OF HIGHWAY ROUTE AT THE LEVEL OF PRELIMINARY DESIGN

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Abstract. *The main goal of the research conducted in this paper is to explain on a real life example the role and importance of the multi-criteria decision-making method. By application of multi-criteria analysis method and ranking the most favourable variant solution for E-763 highway route at the entrance to Belgrade was chosen. VIKOR and Promethee II methods have been used. Ranking has been made based on 20 criteria which make the evaluation basis of each alternative. In this way the methods proved successful tools when choosing the most favourable alternative. The theoretical assumptions of VIKOR and PROMETHEE-GAIA methodologies have been presented in the paper. The calculation has been made by applying VIKOR programme package and Decision Lab programme and then the results obtained were subsequently analyzed.*

Key words: *multi-criteria decision-making, VIKOR method, Promethee II method, ranking.*

1. INTRODUCTION

The majority of technological decision-making problems belong to the group of multi-criteria decision-making problems, which is performed for discreet systems with multi-criteria ranking of alternatives and choosing of optimum compromise solution. As with the definition of the notion of decision-making, so with the process of decision-making the following stages are differentiated [1]: identification and definition of a problem, determination of the set of alternative solutions (*Ai*), determination of the set of criteria to evaluate alternatives (*Cj*), alternative evaluation and finally the choice of alternative.

The criteria on whose basis the choice is made are often mutually conflicting (for instance, better quality implies higher price). In addition to real values of criteria according

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to which the decision is made, the choice of optimum solution depends also on the decision-maker, i.e. on his individual preferences [19].

In order for the decision-making process to be simplified, many mathematical methods have been suggested. Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) represents one of the most often used methods of multi-criteria decision-making. In addition to this method, other methods are also present (AHP, ELECTRE, VIKOR) which take the important place in mathematical description of complex processes in decision-making. All these methods have one main task and this is to help the process of evaluation of available alternatives. VIKOR and PROMETHEE-GAIA methods are used in this paper.

2. Methods of Multi-Criteria Decision-Making

2.1. VIKOR method

VIKOR method (Multicriteria compromise solution) complete with programme package (VIKOR) solves optimization tasks with many heterogeneous and conflicting criteria. The solution obtained can be either unique or it can represent a set of proximate solutions. The compromise solution is that permissible solution which is closest to the ideal one. The ideal solution is determined based on the best values of criteria and is not usually a part of the given set of alternative solutions.

2.2. VIKOR method operating algorithm

It is necessary to rank alternative solutions $a_1, a_2, \ldots, a_j$ with the set values of criteria functions f_{ij}, $i = 1,n$ and $j = 1,J$, where n is the number of criteria and J is the number of alternatives. The ranking procedure goes as follows:

a) The best f_i^* and the worst f_i^- values for all $i = 1,2....n$ criteria functions are determined;

$$f_i^* = \max_j f_{ij}\,;\ \ f_i^- = \min_j f_{ij}\,,\quad \text{if } i\text{-th function represents again} \tag{1}$$

$$f_i^* = \min_j f_{ij}\,;\ f_i^- = \max_j f_{ij}\,,\ \text{if } i\text{-th function represents the costs} \tag{2}$$

b) Based on S_j and R_j measures, the alternative solutions are ranked and the position of a_j on $s(a_j)$ and $r(a_j)$, ranking lists are determined, whereas $s(a_j)$ and $r(a_j)$, j=1,2...J values are calculated using the following relations:

$$S_j = \sum_{i=1}^{n} \omega_i (f_i^* - f_{ij})/(f_i^* - f_j^-)\ \ (\text{for p=1}) \tag{3}$$

$$R_j = \max_i \omega_i (f_i^* - f_{ij})/(f_i^* - f_i^-)\ \ (\text{for p=}\infty) \tag{4}$$

where: n – number of criteria, ω_i – weight of i-th criterion and expresses the preference of a decision-maker, i.e. relative importance of a criterion, S_j – measure of distance $R\ (F,1)$ from an ideal point for alternative j and R_i – measure of distance $R(F,\infty)$ from ideal point for alternative j. Ranking according to S_j and R_j measures results in two ranking lists of alternatives. In order to obtain an integrated ranking list, compromise programming is applied according to which S_j and R_j are now criterion functions. New ranking measure is:

$$Q_j = vQS_j + (1-v)QR_j = v\frac{S_j - S^*}{S^- - S^*} + (1-v)\frac{R_j - R^*}{R^- - R^*} \tag{5}$$

where: $S^- = \max_j S_j$ and $R^- = \max_j R_j$ (6)

$v = (n+1)/2n$ – difficulty of group benefit decision making strategy (7)

$(1-v)$ – difficulty of individual dissatisfaction (8)

QS_j and QR_j represent normalized values. From multicriteria point of view, alternative a_j is better than alternative a_k, if $Q_j<Q_k$ and is ranked higher on the list.

c) VIKOR method suggests as the best alternative from the multicriteria point of view the one which is at the first place of the compromise ranking list for $v = 0.5$ only if it holds:

- (C1) – "sufficient advantage" over the alternative from the next positions. The difference between Qj measures is used for evaluation of the "advantage". Alternative a' has a sufficient advantage over the next position on the ranking list a'' if:

$$Q(a'') - Q(a') \geq DQ \tag{9}$$

where DQ is "the threshold of advantage". The threshold for cases with small number

$$DQ = \min(0.25;\ 1/(J-1)) \tag{10}$$

of alternatives is limited by 0.25.

- (C2) – "sufficiently stable" first position with the change of difficulty v (for v=0.25 and v=0.75). Alternative a' must also be ranked by QS and/or QR.

If some of the conditions are not fulfilled, the set of compromise solutions is formed which includes the first alternative and the next following it. If the first alternative does not fulfil only the condition (C2), then the set of compromise solutions includes only the second one from the compromise ranking list. If it does not fulfil the condition (C1), then the set of compromise solutions contains alternatives from compromise ranking list up to the one which fulfils the condition that the first alternative does not have sufficient advantage over that particular alternative. The results of the VIKOR method are ranking lists according to measures QR, Q (for $v = 0.5$) and QS and a compromise alternative or a set of compromise solutions. These results represent a basis for decision-making and adopting of the most favourable (multicriteria optimum) solution.

2.3. PROMETHEE- GAIA method

PROMETHEE method bases on mutual comparison of every pair of alternatives according to every chosen criterion respectively. GAIA visual interactive modulation represents graphic interpretation of the PROMETHEE method. In order for the alternative ranking to be made according to the PROMETHEE method, it is necessary upon having defined the criteria to define also the *P(a,b)* preference function for alterantives *a* and *b*. Alternatives *a* and *b* are evaluated according to criteria functions. Alternative *a* is considered better than alternative *b* according to criterion *f*, if $f(a) > f(b)$.

Based on such a comparison the decision-maker has a possibility to assign preference to one of the alterantives. The preference can take any value within the interval ranging from 0 to 1, and relationship combinations are possible to be represented by the following relations:

$$P(a, b) = 0 \textit{ no preference, indifference}, \tag{11}$$

$$P(a, b) \approx 0 \textit{ weak preference } k(a) > k(b), \tag{12}$$

$$P(a, b) \approx 1 \textit{ strong preference } k(a) >> k(b), \tag{13}$$

$$P(a, b) = 1 \textit{ strict preference } k(a) >>> k(b). \tag{14}$$

The relations are within the following limits:

$$0 < P(a,b) > 1, \tag{15}$$

$$P(a,b) \neq P(b,a). \tag{16}$$

Greater preference is expressed by greater value from the given interval. This means that for each criterion the decision-maker considers certain preference function [3]. Figure 2 shows six generalized criteria, six preference functions $P(d)$. It is possible to represent all six generalized criteria with linear functions, i.e. they are obtained by the choice of four points at the most within the criterion space of the given criterion. In addition to criterion functions, Figure 2 shows also the parameters for the given points chosen within the criterion space shown at *x*-axis (d), while the degree of preference is given on *y*-axis. For IV-degree criterion instead of the value $P(d) = ½$, it is possible to assign any value $0 < P(d) < 1$ [2]. The decision-maker must identify one alternative optimizing all criteria. The main data of multi-criteria problem are given in Decision-Making Table (Figure 1).

a	$g_1(\cdot)$	$g_2(\cdot)$	...	$g_j(\cdot)$	...	$g_k(\cdot)$
a_1	$g_1(a_1)$	$g_2(a_1)$	...	$g_j(a_1)$	...	$g_k(a_1)$
a_2	$g_1(a_2)$	$g_2(a_2)$	...	$g_j(a_2)$	...	$g_k(a_2)$
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
a_i	$g_1(a_i)$	$g_2(a_i)$	...	$g_j(a_i)$	...	$g_k(a_i)$
.	.	.	.	.	.	
.	.	.	.	.	.	
.	.	.	.	.	.	
a_n	$g_1(a_n)$	$g_2(a_n)$	...	$g_j(a_n)$	...	$g_k(a_n)$

Fig. 1 Decision-Making Table

Figure 2 uses the following designations: m – indifference limit, n – limit of strict preference, σ – mean value between m and n for Gauss criterion. Upon having defined the type of general criterion, it is necessary to determine the value of action preference function *a* in relation to *b* according to each criterion and to calculate the preference index (IP) of *a* action in relation to *b* action. Each pair of actions is within the set A. The Preference Index is calculated in the following manner:

$$IP(a,b) = \sum_{j}^{n} W_j P_j(a,b), b \sum W_j = 1 \tag{17}$$

where: *Wj* – weight of j^{-th} criterion.

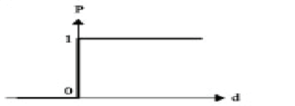
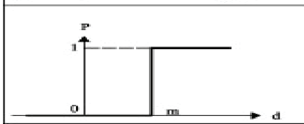
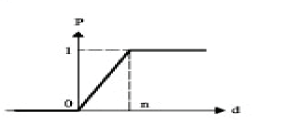
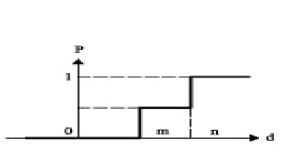
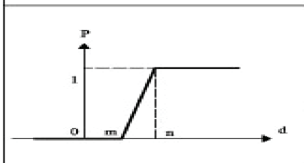
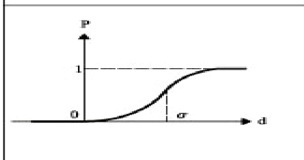
	Type I - Common criterion $P(d) = \begin{cases} 0, d \leq 0 \\ 1, d > 0 \end{cases}$	–
	Type II - Quasi criterion $P(d) = \begin{cases} 0, d \leq m \\ 1, d > m \end{cases}$	m
	Type III - Criterion with linear preference $P(d) = \begin{cases} 0, d < 0 \\ d/n, 0 \leq d \leq n \\ 1, d > n \end{cases}$	n
	Type IV - Level criterion $P(d) = \begin{cases} 0, d \leq 0 \\ 1/2, m < d < n \\ 1, d \geq n \end{cases}$	m,n
	Type V - Criterion of linear preference with indifference area $P(d) = \begin{cases} 0, d \leq m \\ \frac{d-m}{n-m}, m < d \leq n \\ 1, d > n \end{cases}$	m,n
	Type VI - Gaus criterion $P(d) = 1 - e^{-\frac{d^2}{2\sigma^2}}$	σ

Fig. 2 Types of preference function P(d) with the parameters describing them

If it happens that all criteria have the same weight, in other words that *Wj =1/ n,* then the preference index is:

$$IP(a,b) = \left(\frac{1}{n}\right) \sum_{j}^{n} P_j(a,b) \tag{18}$$

for which the following relation is valid:

$$0 \leq P_j\,(a,b) \leq 1. \tag{19}$$

After determining the preference index *IP(a,b)*, it is finally possible to calculate the alternative flow index *T(a),* the value of which represents the validity of the alternative. Based on this index the final decision is made on logistic competence of one alternative from the considered set of alternatives. It is determined as:

$$T(a) = \frac{\sum_{x \in A} IP(x)}{i-1} \tag{20}$$

When choosing the criteria which are entered into the decision-making base, one should take into account that the higher number of different criteria defines the problem comprehensively and objectively in accordance with the requirements set by the decision-maker [13]. In this way the influence of experience and subjective evaluation of the decision-maker on choosing generalized criteria is reduced to the minimum. In other words, it is made based on the method of the smallest square so that the generalized criterion is chosen at which the sum of squares of experimental points' aberration from the theoretical curve of the generalized criteria is the smallest.

3. Review of Variant Solutions Evaluation

3.1. Subject of analysis

The subject of the analysis in this paper is the evaluation of two variant solutions of the preliminary design of E-763 highway entrance into Belgrade by either the right (DOS) or left (LOS) bank of the Sava River with the goal to define the optimum one. In order for this process to be adequately realized, it is necessary to establish the reliable documentation foundation which is processed in detail while the goals and criteria according to which the comparison will be made should be clearly defined.

3.1.1. Variant of the highway going along the right bank of the Sava River – DOS variant

A highway variant devised by Preliminary design to be on the right bank of the Sava River begins at Ostruznica. It is divided into two sections: Ostruznica – Umka, which is 6.75 km long, and Umka – Obrenovac, which is 7.7 km long. The total length of two highway sections designed according to this variant is 14.45 km. At the first section of the highway there is a superstructure at the half of the cross-section of the future highway along the entire length of the section. The highway route stretches and follows regarding both the layout and levelling the already built half of the highway. This section has several bridges. The biggest bridge is in located the road bed at Ostruznica and it is 545 m long. At the end of the section there is a grade separated cross roads "Umka" designed and two flyovers 100 m and 101 m long respectively.

As for the facilities for the highway users, there are gas stations provided at km 5 + 690 on both sides. Other infrastructure includes toll station, with 8 + 13 toll booths and toll station at the Umka trumpet with 4 toll booths.

The second section from Umka to Obrenovac is 7.6 km long. It goes from grade separated cross-roads of the well known landslide Umka-Duboko which should be stabilized. Horizontal curve radii range from 750 m to 5000 m. Longitudinal gradient ranges from 0.2% to 2%. Highway route is within the embankment along the entire section. The embankment height is changing and ranges from 2-3 m up to over 20 m in the Sava riverbed. Where there is low bearing capacity soil in the highway roadbed the Styrofoam filling is envisaged in order to reduce the undersoil load. On this section the grade separated trumpet cross road Obrenovac is designed and as for the larger structures there is a flyover the principal state highway M-19, a flyover for the entrance into Prva iskra factory with 60 m span and several bridges with up to 10 m span.

3.1.2. Variant of highway on the left bank of the Sava River – LOS variant

This variant starts from grade separated cross roads Surcin at the intersection of E-763 highway and by-pass road around Belgrade and cargo by-pass railroad Batajnica – Ostruznica – Pancevo and ends at the territory of Obrenovac, where it crosses the bridge over the Sava and Kolubara Rivers and fits into the highway route built by the Institute for Roads from Belgrade. The total length of this section is 17.2 km.

The bridge over the Sava and Kolubara Rivers is the most important facility at this section. The bridge is designed in the direction with the vertical alignment of the highway which enables unobstructed passage of ships at the level of high river water (76.00 m).

The grade separated crossroads Surcin is designed as a double trumpet, at the connection of E-763 highway (Belgrade – Southern Adriatic) with the by-pass highway E-70/E-75. As the extension to the Belgrade-Southern Adriatic highway towards Novi Beograd the city arterial road is designed this directs the traffic from the highway into the city which did not turn to the by-pass highway. City arterial road is an integral part of the highway design, since it is through this road that the traffic goes to all parts of the city by means or over the internal ring road (UMP), T-6 road and Northern tangent (the bridge on the Danube in Zemun) and "highway" through Belgrade. In the area of grade separated crossroads Surcin the E-763 highway route intersects cargo by-pass railroad which it passes by the flyover as well as the principal gas pipeline MG-05.

Grade separated crossroads, Obrenovac loop, has been designed as trumpet with priority direction Obrenovac – Belgrade. The toll station at the highway is located at the junction road from the highway to the existing principal road (arterial road M-19) Belgrade – Obrenovac. At the left bank of the Sava River from the bridge to the by-pass road there are several protected areas of springs and Reny wells besides the Sava River, which are by-passed with this design solution.

The vertical alignment of the highway at this section has been designed in such a way that the entire highway is within the embankment, some 2 – 2.5 m above the existing terrain. The designed inclination of the vertical alignment is 2%. At the intersections of the highway with the local roads on the left bank of the Sava River, there are sharp inclinations of the vertical alignment provided on these roads (3-4%, in order to reduce the construction costs). The site plan of both designed variants is shown in Figure 3.

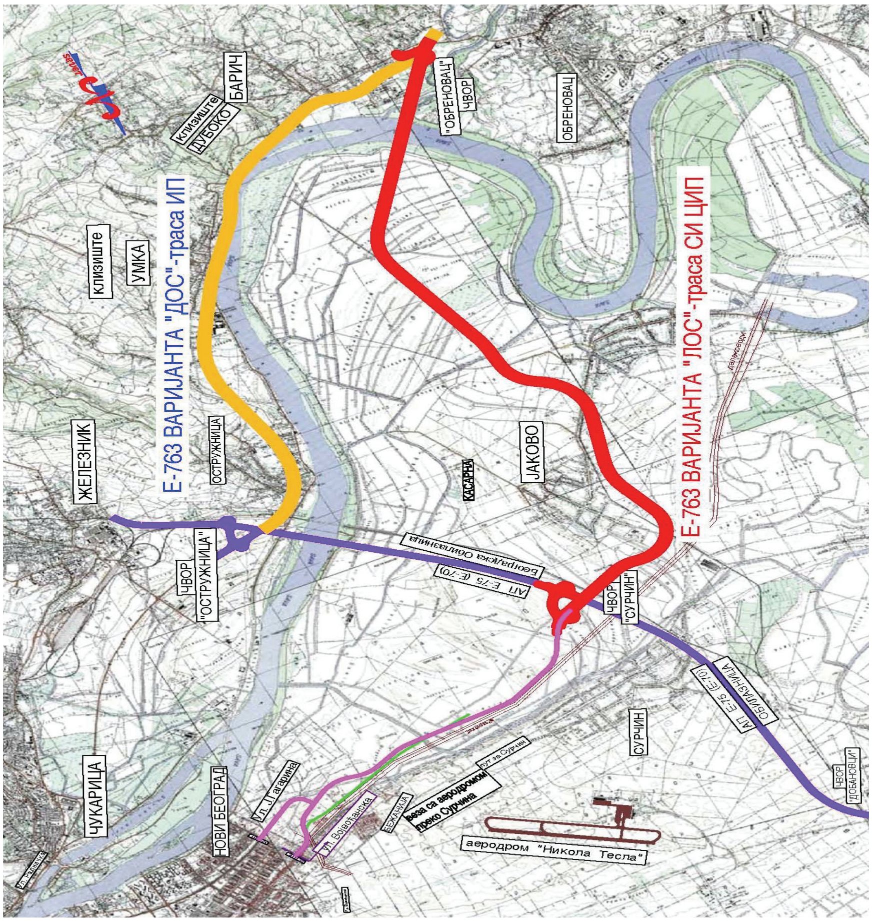


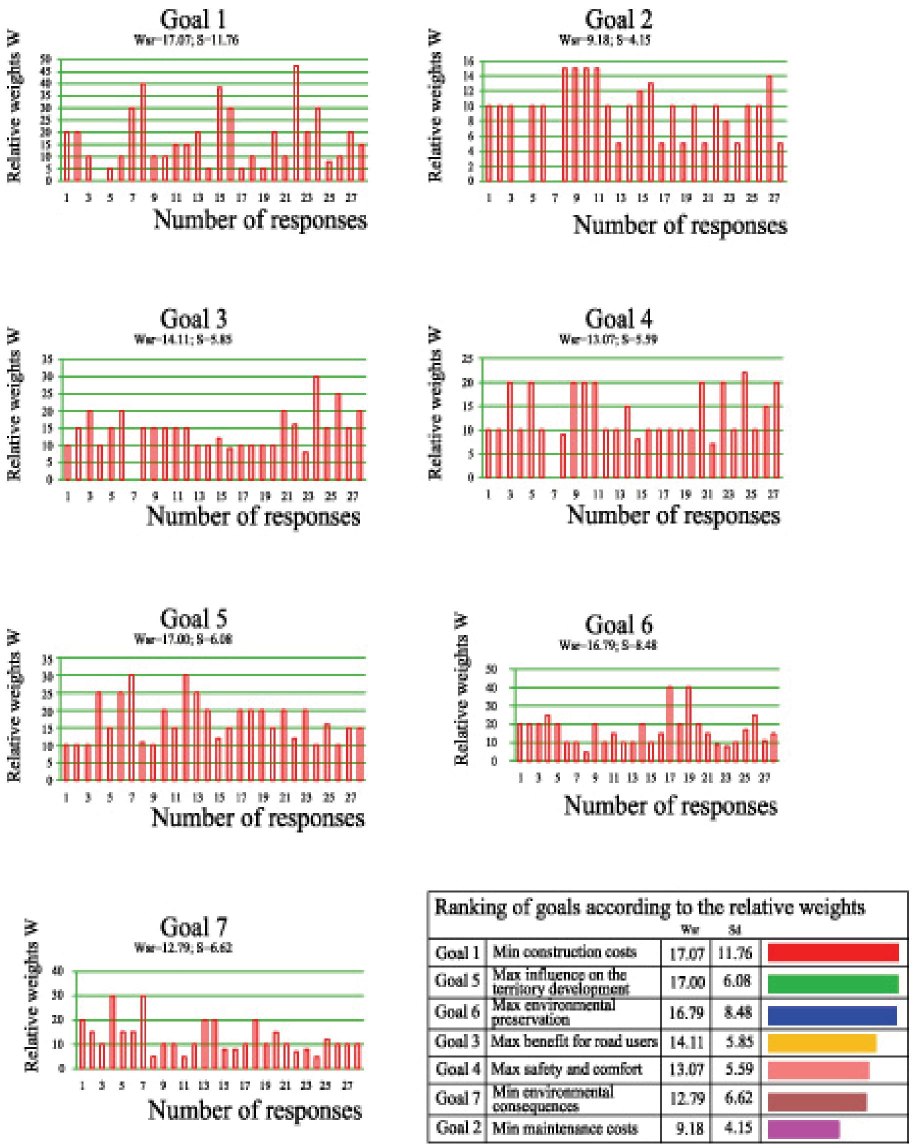
Fig. 3 Variant solutions of highway routes (DOS and LOS)

3.2. Defining evaluation goals, criteria and indicators

The first and the most important step in the process of variant evaluation is to define goals and criteria of evaluation and their relative weights which are numerical reflection of the importance of goals or criteria. The following goals have been defined:

1. ***Minimum*** construction costs
2. ***Minimum*** maintenance costs
3. ***Maximum*** benefit for road users
4. ***Maximum*** safety and comfort
5. ***Maximum*** influence on the area development
6. ***Maximum*** preservation of the environment
7. ***Minimum*** environmental consequences

For goal relative weights the simplified Delphi method has been applied at the sample of 28 respondents (11 graduate construction engineers, 3 graduate traffic engineers, 4 graduate urban planners and 10 respondents of other professions). The results of statistical data processing are shown in Figure 4.



		Wsr	Sd	
Goal 1	Min construction costs	17.07	11.76	
Goal 5	Max influence on the territory development	17.00	6.08	
Goal 6	Max environmental preservation	16.79	8.48	
Goal 3	Max benefit for road users	14.11	5.85	
Goal 4	Max safety and comfort	13.07	5.59	
Goal 7	Min environmental consequences	12.79	6.62	
Goal 2	Min maintenance costs	9.18	4.15	

Fig. 4. The results of statistical processing of gathered data

Table 1 shows the goal, criteria and indicator matrix with relative weights and values of criteria functions.

Table 1 Matrix of goals, criteria, indicators and weights of criteria functions

Highway construction goals	Goal weight W	Criterion	Criterion weight W_c	Ext.	Indicators	Unit of measurement	Indicator weight W_i	Variant "LOS" $L=14.5$ km		Variant "DOS" $L=17.2$ km		Criterion function weight f_i	Criterion function weight f
1 Min construction costs	0.171	C.1.1 Expropriation and population displacement		MIN.	I 1.1.1 Town and country building land				146 286 521		138 659 357	f 1	0.171
					I 1.1.2 pasture-grounds and meadows	€							
		C.1.2 Superstructure			I 1.2.1 Road surface - route	€							
					I 1.2.2 Road surface – cross roads	€							
		C.1.3 Road bed			I 1.3.1 Cuttings	€							
					I 1.3.2 Embankments	€							
					I 1.3.3 Drainage	€							
		C.1.4 Engineering structures and facilities			I 1.4.1 Standard and non-standard bridge structures, tunnels, galleries, culverts, supporting and retaining curtain walls, displacement of roads and railroads, regulation of water flows, auxiliary facilities	€							
		C.1.5 Signalization and equipment			I 1.5.1 Horizontal and vertical signalization	€							
2 Min maintenance costs	0.092	C.2.1 Regular maintenance		MIN.	I 2.1.1 Regular road maintenance	€		26 779 553	28 418 993	22 385 452	23 581 702	f 2	0.092
		C.2.2 Periodic maintenance			I 2.2.1 Periodic road maintenance	€		1 355 640		957 000			
		C.2.3 Winter maintenance			I 2.3.1 Average conditions of winter maintenance	€		283 800		239 250			
3 Max benefit for road users	0.141	C.3.1 Intensity of traffic flows	0.25	MIN.	I 3.1.1 Passenger cars	Veh./day	0.40	5362 041	3 667 005	5 275 581	3 599 830	f 3	0.035
					I 3.1.2 Cargo vehicles	Veh./day	0.15	445 751		418 883			
					I 3.1.3 Total	Veh./day	0.25	5 807 792		5 694 465			
						km	0.20	16 892		15 745			
		C.3.2 Travelling time of all vehicles of the network	0.30	MIN.	I 3.2.1 Total	h	0.55	84 753	46 725	86 020	55.21	f 4	0.042
						h/km	0.45	245.7		237.1			
		C.3.3 Transport work of all vehicles of the network	0.15	MIN.	I 3.3.1 Total	Vehkm	0.60	4 864 952	2 924 605	5 026 815	3 021 623	f 5	0.021
						Vehkm km	0.40	14 086		13 836			
		C.3.4 Average speed of all vehicles of the network	0.30	MAX.	I 3.4.1 Total	km/h	1.00	54.34	54.34	55.21	55.21	f 6	0.021

4 Max safety and comfort	0.13	C.4.1 Number of traffic accidents	1.00	MIN.	I 4.1.1 Traffic accidents with fatalities	No/km/year	0.75	1.11	2.84	1.25	3.18	f 7	0.130
					I 4.1.2 Traffic accidents with the injured persons	No/km/year	0.20	6.1		6.80			
					I 4.3.1 Traffic accidents with material damage	No/km/year	0.05	15.8		17.80			
5 Max influence on the territorial development	0.17	C.5.1 Influence on economic development	0.60	MAX.	I 5.1.1 Stimulation of economic activities	Common scale	0.35	5	4.85	6	5.90	f 8	0.102
					I 5.1.2 Income increase		0.35	5		6			
					I 5.1.3 Change in employment structure		0.20	4		5			
					I 5.1.4 Increase of land renting potential		0.05	5		7			
					I 5.1.5 Change of real estate value		0.05	6		5			
		C.5.2Remedy and revitalization of degraded locations	0.40		I 5.2.1 Territorial redistribution of population	Common scale	0.15	4	6.00	5	4.75	f 9	0.068
					I 5.2.2 Preservation of the existing settlements		0.25	9		4			
					I 5.2.3 Stimulation of urban planning and construction		0.25	7		5			
					I 5.2.4 Increasing quality of life		0.35	4		5			
6 Max environmental protection	0.168	C.6.1Noise	0.18	MIN.	I 6.1.1 Route length through the settlement and the one affecting it	km	0.60	9.04	5.94	0.39	0.30	f 10	0.030
					I 6.1.2 The settlement in the zone of influence		0.40	0.13		0.16			
		C.6.2 Air pollution	0.16	MIN.	I 6.2.1 Route length through settlements and forests	km	0.60	10.32	7.86	2.03	6.84	f 11	0.027
					I 6.2.2 Route length through agricultural land		0.40	4.18		14.05			
		C.6.3 Water pollution	0.18	MIN.	I 6.3.1 Route length through the zone of spring protection	km	0.60	5.81	5.25	10.63	6.63	f 12	0.030
					I 6.3.2 Water flows in the zone of influence		0.40	4.42		0.63			
		C.6.4 Soil pollution	0.16	MIN.	I 6.4.1 Route length through agricultural land	km	0.60	4.18	3.46	14.05	9.10	f 13	0.027
					I 6.4.2 Route length through forests		0.40	2.38		1.68			
		C.6.5 Flora and fauna	0.15	MIN.	I 6.5.1 Route length through forests	km	0.60	2.38	5.96	1.68	6.88	f 14	0.025
					I 6.5.2 Water-courses in the zone of influence, route length through meadows and agricultural land		0.40	11.32		14.68			
		C.6.6 Resources	0.17	MIN.	I 6.6.1 Quantity of stone	10^6 m^2	0.60	1.51	2.37	0.00	1.14	f 15	0.029

7 Min environmental consequences	0.128	C.7.1 Natural limitations	0.50	min	I.7.1.1 Route length on landslides	km	0.45	4.20	3.36	0.00	1.00	f 16	0.064
					I.7.1.2 Route length on terrain with high underground water		0.20	0.00		5			
					I.7.1.3 The route moves the Sava riverbed and enters the navigation route		0.35	4.20		0.00			
		C.7.2 Spatial and settlement limitations	0.35	min	I.7.2.1 Number of inhabitants within the corridor	1000ti	0.25	19	19	10	10	f 17	0.011
					I.7.2.2 Route length in settlements	km	0.40	8	4.4	0	2.8	f 18	0.027
					I.7.2.3 Route length through agricultural and forest land	km	0.20	6		14			
					I.7.2.4 Number of protected cultural monuments	units	0.15	4	4	2	2	f 19	0.007
		C.7.3 Infrastructural limitations	0.15	min	I.7.3.1 Number of intersections with first class state roads	units	0.20	2	1.1	1	1.15	f 20	0.019
					I.7.3.2 Number of intersections with second class state roads		0.10	1		0			
					I.7.3.3. Number of intersections with railroads		0.20	1		1			
					I.7.3.4. Number of intersections with electric transmission lines		0.05	3		2			
					I.7.3.5. Number of intersections with rivers		0.20	0		2			
					I.7.3.6. Number of intersections/affecting springs within the corridor		0.25	1		1			

3.3. The choice of optimum variant route obtained by the VIKOR method

Based on the determined methodology, comparison of goals, criteria and indicators with the corresponding relative weights by the VIKOR method the following results have been obtained:

Input data are from losdos.inp

763 HIGHWAY BELGRADE-OBRENOVAC
Multicriteria ranking: 2 alternatives according to 20 criteria
List of alternatives: A 1. DOS   A 2. LOS
List of criteria
f 1. Construction costs (Eur)
f 2. Maintenance costs (Eur)
f 3. Traffic Flow Intensity (vehicle/day)
f 4. Travelling time of all vehicles on the network (h) (h/unit)
f 5. Transport work of all vehicles on the network (vehicle/km)
f 6. Average speed of all vehicles on the network (km/h)
f 7. Number of traffic accidents (unit/km/year)
f 8. Influence on economic development (ord. scale)
f 9. Improvement and revitalization of degraded locations
f 10. Noise (km)
f 11. Air pollution (km)
f 12. Water pollution (km)
f 13. Soil pollution (km)
f 14. Flora and fauna (km)
f 15. Resources (10^6m3)
f 16. Natural limitations (km)
f 17. Number of inhabitants of the settlements within the corridor (inhabitants)
f 18. Route in settlements on agricultural and forestry land
f 19. Number of protected cultural monuments (pcs)
f 20. Infrastructural limitations (pcs)

Ranking lists per measures: QR, Q and QS
QR – Minimax strategy, Q – Compromise, QS – Majority benefit

R.L.QR	R.L.Q and Q(J)	R.L.QS
A 2 0.130	A 2 0.000	A 2 0.362
A 1 0.171	A 1 1.000	A 1 0.638

RANKING LIST
1. 0.000 LOS
2. 1.000 DOS

Compromise solution for final decision
***A 2. LOS Advantage* = 100.0 %**

The results of the VIKOR method evaluation based on the presented criteria suggest that the variant of the route on the left bank of the Sava River (LOS) has sufficiently stable first position and sufficient advantage in comparison with the variant of the route on the right bank of the Sava River (DOS).

3.4. Choosing the optimum variant of the route by PROMETHEE-GAIA method

For the calculation of the stated example Decision Lab software was used which can graphically show the results of ranking alternatives. Figure 5 presents the initial (tabular) data in the given software.

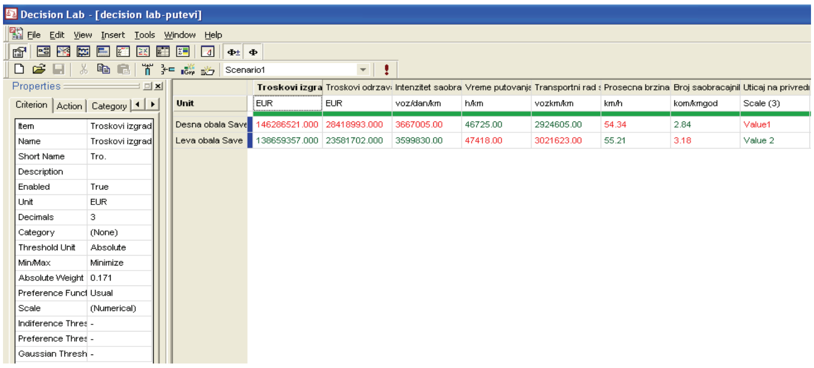


Fig. 5 Initial data for alternatives and criteria

Specialized software for data processing D-Sight was used for the analysis of the results. The platform on which D-Sight is being developed is closely connected with the PROMETHEE method. D-Sight program enables simplification of the PROMETHEE analytical model method through the following steps: input of alternatives, input of criteria, input of weight coefficients for individual criteria, input of alternative weights and their normalization, determination of criteria functions and maximization or minimization of criteria and finally the result reading [12].

The graphic representation of result processing has been obtained using Global Visual Analyses (GVA) tool and it is shown in Figure 6. The information related to the complex problem of decision-making which includes k criterion can be represented in k-dimensional space. GAIA plane represents the plane which is obtained by projection of the entire information into two-dimensional space. The alternatives are represented as triangles, and the criteria as squares in GAIA plane. The red dot represents the approximate value of all criteria weights and visually represents an optimum point to which the offered alternatives strive. Conflicting criteria characteristics are shown in the diagram; conflicting criteria are oriented in the opposite direction, while the criteria of similar preference are oriented in the same direction. As an addition in representing alternatives and criteria, the projection of weight vectors in GAIA plane has a corresponding Pi vector which shows the direction of compromise results. A large number of offered alternatives have resulted in clustering and lack of clearness of graphic representation of the results obtained in Figure 6.

By reading the solutions obtained by the application of the PROMETHEE method of multi-criteria decision-making with the support of D-Sight software it is graphically confirmed that LOS has the strongest $T(a)$ index.

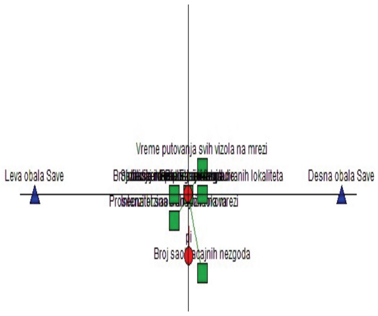


Fig. 6 Graphic representation of result processing using D-sight software

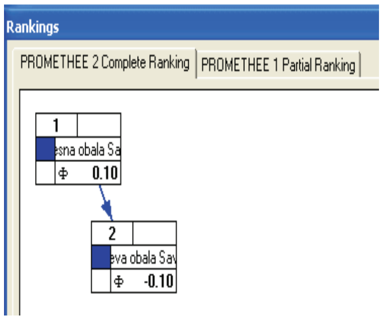


Fig. 7 Advantages and disadvantages of the left and right banks of the Sava River per criteria

PROMETHEE II method makes it possible for the decision-maker to rank alternatives completely. Figure 7 shows the advantages and disadvantages of both the left and right banks of the Sava River per criteria. PROMETHEE I and PROMETHEE II methods do the ranking based on the assigned weight coefficients. Special option of the software called THE WALKING WEIGHTS enables to modify the initial weights and to observe the resulting modifications when ranking using PROMETHEE II method (Figure 8). In this way the decision-maker can rather simply analyze the sensitivity of the obtained results. Figure 9 shows the influence of offered alternatives on the project costs.

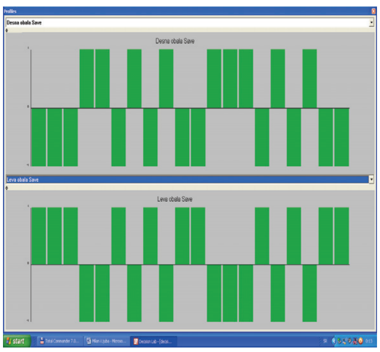


Fig. 8 WALKING WEIGHTS option by which the result sensitivity analysis is carried out

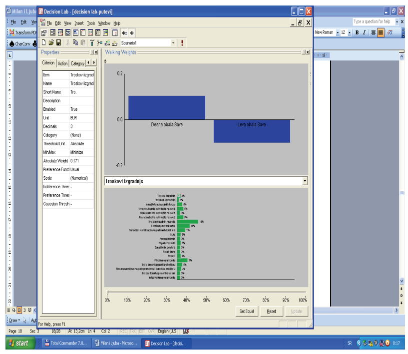


Fig. 9 Influence of alternatives on project costs

4. CONCLUSION

The main goal of the research conducted in this paper is to determine the advantages of a certain section using multi-criteria analysis. The VIKOR and PROMETHEE methods were used as a mathematical tool. The paper has stated theoretical bases of these methods and showed their practical application giving the example of ranking of variant solutions of the highway preliminary design. The results obtained show that both methods confirm that the variant of the route on the left bank of the Sava River (LOS) is more favorable when compared with the variant of the route on the right bank of the Sava River (DOS) and that it represents an optimum solution of entrance of E-763 highway into Belgrade.

Besides the undisputed quality, it should be pointed out that the successfulness of the application of the VIKOR and PROMETHEE methods in the decision-making process largely depends on the decision-maker's capabilities and experience. The decision-maker should be capable of determining the importance of each respective criterion and quantify it on an interval scale. If the pre-conditions have been fulfilled both the VIKOR and PROMETHEE methods become powerful tools in the hands of decision-makers which offer strong support in solving complex problems of multi-criteria decision-making.

REFERENCES

1. Baračkai, Odlučivanje o poslovnim strategijama, Svjetlost, Sarajevo, 1987.
2. Brans, J.P, Mareschal, B., Ph. Vincke, How to select and how to rank projects: The PROMETHEE method. European Journal of Operational Research, 24(2): 228–238, 1986.
3. Brans, J.P, Mareschal, B., The PROMETHEE VI procedure. How to differentiate hard from soft multicriteria problems. Journal of Decision Systems, 4:213–223, 1995.
4. Brans, J.P, Mareschal, B., Promethee V – MCDM problems with segmentation constraints. INFOR, 30(2): 85–96, 1992.
5. Brans, J.P, Mareschal, B., The PROMETHEEGAIA decision support system for Multicriteria investigations. Investigation Operativa, 4(2): 107– 117, 1994.
6. Brans, J.P., L'ingénièrie de la décision; Elaboration d'instruments d'aide à la décision. La Method PROMETHEE. In R. Nadeau and M. Landry, editors, L'aide à la décision: Nature, Instruments et Perspectives d'Avenir, pages 183–213, Québec, Canada, 1982. Presses de l'Université Laval.
7. Cvetković, M., Cvetković, S., Višekriterijumsko odlučivanje o izboru lokacije pri izgradnji mini hidroelektrana primenom Promethee-gaia metodologije, MIT Vrnjačka banja, 28.08.2011. ISBN 978-86-7412-052-1
8. Cvetković, S., Cvetković,M. Izbor lokacije trgovinskih centara, Četvrti simpozijum sa međunarodnim učešćem, TRANSPORT I LOGISTIKA, TIL, Niš 27.maj 2011 (83-86), ISBN 978-86-6055-014-1
9. Davignon, G., Mareschal, B. Specialization of hospital services in Quebec – An application of the PROMETHEE and GAIA methods. Mathematical and Computer Modelling, 12(10-11): 1393–1400, 1989.
10. D-sight, software for Windows based on the PROMETHEE GAIA methodology, 2011.
11. Hunjak, T., Kvantitativne metode u menadžmentu izbor softver- a za KMS, Pristupni rad, Varaždin, 2006.
12. Kolarević, M., Brzi razvoj proizvoda, Zadužbina Adrejević, Beograd, 2004
13. Kolli, S., Parsaei, H.R. Multicriteria analysis in the evaluation of advanced anufacturing technology using PROMETHEE. Computers & Industrial Engineering, 23 4, 455–458, 1992.
14. Marković, Lj., Milić Marković, Lj.,Ćirović, G., Application of Multicriteria Optimization in Designing Railway Line at the level of The Main Project, CETRA - 2nd International Conference on Road and Rail Infrastructure, Dubrovnik, 7-9 May 2012, Croatia
15. Marković, Lj., Milić Marković, Lj. - Definisanje ciljeva i određivanje težina kriterijuma u postupku vrednovanja varijantnih rešenja primenom višekriterijumske optimizacije u procesu projektovanja saobraćajnica, SYM-OP-IS 2010 - XXXVII Simpozijum o operacionim istraživanjima, Tara, 2010.
16. Nikolić, I., Borović S., Višekriterijumska optimizacija, metode, primena u logistici,softver, CVŠ VJ, Beograd, 1996.
17. Opricović, S. Višekriterijumska optimizacija sistema u građevinarstvu, Građevinski Fakultet Univerziteta u Beogradu, Beograd 1998
18. Opricović, S., G.H. Tzeng, – Extended VIKOR method in comparison with outranking, European Journal of Operational Research 178, No.2, pp. 514-529, 2007.
19. Prvulović S., Tolmač D., Nikolić Dj., Primena PROMETHEE II - metode u dijagnostici Uspešnosti proizvoda od gume. Tenicka dijagnostika, 3, 23-28, 2008.
20. Prvulović, S., Manasijević, D., Teorija odlučivanja sa primerima, Bor, 2007.

21. Saobraćajni institut CIP - Idejni projekat autoputa E-763, na deonici od Beograda do Obrenovca, trasom po levoj obali reke Save, Beograd, 2000.
22. Schwab, K., The Global Competitiveness Report 2010–2011. World Economic Forum. Geneva, 2010.
23. Weihrich, K. Essentials of Management, Fifth Edition, McGraw-Hill Publishing Company, New York, 1990.

VIŠEKRITERIJUMSKO ODLUČIVANJE PRI IZBORU VARIJANTNOG REŠENJA TRASE AUTOPUTA NA NIVOU IDEJNOG PROJEKTA

Ljubo Marković, Milan Cvetković, Ljiljana Milić Marković

Osnovni cilj istraživanja sprovedenog u ovom radu je da se na realnom primeru objasni uloga i značaj metoda višekriterijumskog odlučivanja. Primenom metoda višekriterijumske analize i rangiranja izvršen je izbor najpovoljnijeg varijantnog rešenja trase autoputa E-763 na ulasku u Beograd. Korišćene su metode VIKOR i Promethee II. Rangiranje je izvršeno je na osnovu 20 kriterijuma koji čine osnovu vrednovanja svake alternatve. Na ovaj način metode su se pokazale kao uspešan alat prilikom izbora najpovoljnije alternative. Ovde su prezentovane teorijske postavke VIKOR i PROMETHEE-GAIA metodologije. Proračun je izveden primenom programskog paketa VIKOR i Decision Lab programa i izvršena je analiza dobijenih rezultata.

Ključne reči: *višekriterijumsko odlučivanje,metoda Vikor, Promethee II metoda, rangiranje.*