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Draženko Glavić, University of Belgrade, Faculty of Transport and Traffic Engineering, drazenglavic@gmail.com
Marina Milenković, University of Belgrade, marina.milenkovic@sf.bg.ac.rs
Dragan Topić, Putevi i ulice d.o.o. Banja Luka, dragantopic@yahoo.com

MULTI-CRITERIA ANALYSIS OF COMPROMISE ROAD ALIGNMENT SOLUTION FOR ROUTE 2A - SECTION KRUPA TO BOČAC

Abstract

The subject of this analysis is the selection of the road alignment of Route 2a on the section Krupa - Bočac (Republic of Srpska). The complexity of the problem is reflected in the fact that a number of conflicting criteria of different stakeholders should be taken into account; i.e. criteria that are important from the aspect of road managers, criteria from the aspect of users and criteria society as a whole. The PROMETHEE method was used to determine compromise solution. Detailed comparative analysis of all parameters showed that variant 0 of the Krupa - Bočac section is a first ranked compromise solution. Sensitivity analysis has shown that the first place is stable by most criteria. Decision support framework presented in this paper can help future researchers and decision makers with similar problem.

Keywords: MCDM, Route 2a, Criteria, Road alignment.

ВИШЕКРИТЕРИЈУМСКА АНАЛИЗА КОМПРОМИСНОГ РЕШЕЊА ТРАСЕ ПУТА ЗА РУТУ 2А - ДЕОНИЦА КРУПА - БОЧАЦ

Сажетак

Предмет ове анализе је избор трасе руте 2а на деоници Крупа – Бочац (Република Српска), на основу дефинисаних варијантних решења. Комплексност проблема огледа се у чињеници да треба узети у обзир бројне конфликтне критеријуме различитих интересних група – критеријуме који су важни како са аспекта управљача пута, тако и са аспекта корисника и друштва у целини. За решавање овог проблема коришћен је PROMETHEE метод. Детаљном анализом свих параметара утврђено је да је варијанта 0 деонице Крупа - Бочац компромисно прво рангирано решење. Анализа осетљивости је показала да је прво место стабилно по већини критеријума. Оквир за подршку одлучивању приказан у овом раду може послужити истраживачима и доносиоцима одлука приликом решавања сличних проблема.

Кључне ријечи: MCDM, Рута 2а, Критеријуми, Траса пута.

1. INTRODUCTION

1.1. GENERAL DATA ON THE EXISTING ROAD NETWORK

The main road network in the Republic of Srpska (RS) covers about 4,200 km of roads, of which about 3,600 km are roads with modern asphalt pavement. Roads are classified as main roads (approximately 1,900 km) and regional roads (approximately 2,300 km). About 320 km of the main road network are part of the European road network. This basic road network is also increased by 227 km of local roads, which were declared important for the functioning of the total traffic on the territory of the Republic of Srpska by special decisions of the Government of the RS, and handed over to the PE "Roads of the RS" for management.

In terms of importance for network from the transport aspect, there are two main routes in the Republic of Srpska, where most of the transport takes place. These are the northern direction that runs from the borders of Croatia, Novi Grad, through Prijedor, Banja Luka, Derventa, Modriča, Brčko and Bijeljina to the border with the Republic of Serbia and the eastern direction that runs from Bijeljina through Zvornik, Vlasenica, Han Pijesak, Istočno Sarajevo, Rogatica, Novo Goražde, Foča, Gacko to Trebinje, from where it separates towards the borders of Croatia and Montenegro. The total length of the north route is about 335 km, while eastern route is about 390 km.

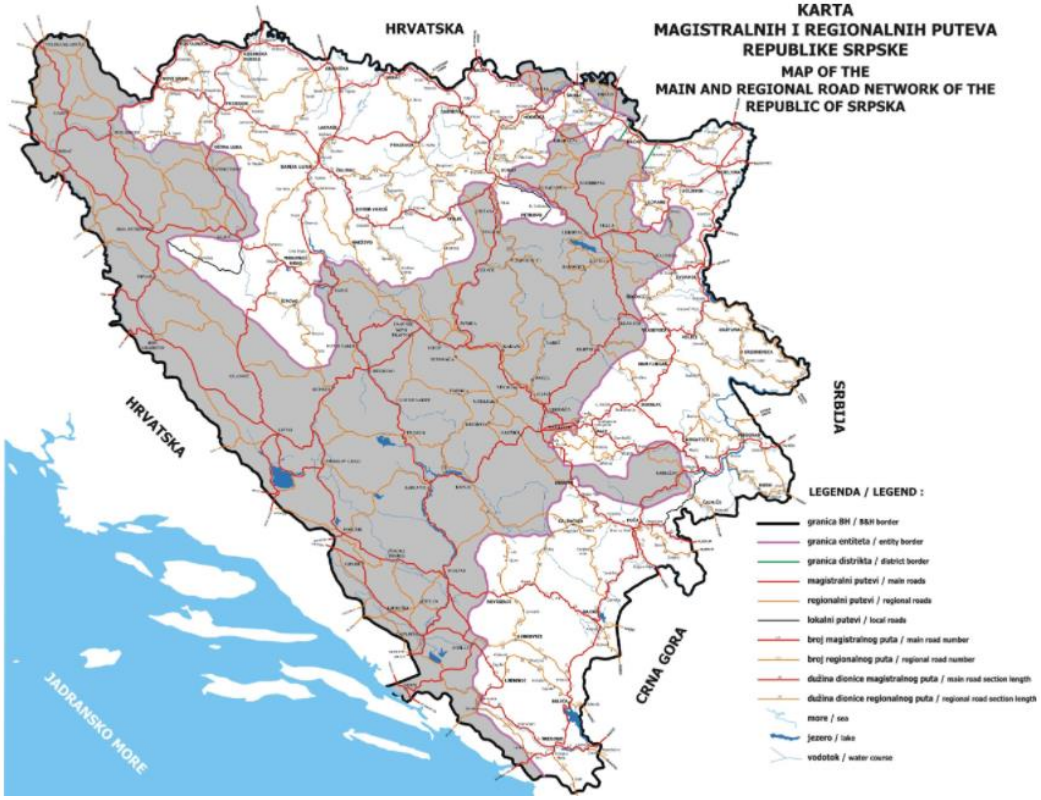

Figure 1. *Road network of Republic of Srpska*

The route of the subject road is located on the area between two local communities, the town Banja Luka and in smaller part, municipality Mrkonjic Grad. SECTION I, II and III of the route Banja Luka – Mrkonjic Grad represent an alignment of the main road M-16 (according to new road classification MI-101), that is at the same time defined within the European road network as E-661. These particular sections of the main road are located on the territory of the Republic of Srpska and therefore are under direct jurisdiction of PE „Roads of RS“ from Banja Luka. The road E-661 (M-16) extends in a north-south direction and it is one of the most important corridor in RS, which connects Banja Luka with Corridor X in the north in Croatia and with the Adriatic Sea in the south. The road E-661 also provides very important regional connection in the RS, Bosnia and Herzegovina (BiH).

The main goal of project is to improve traffic capacity and service levels on the north-south corridor in the RS by reconstructing the existing road M-16 Section II “Krupa – Bočac” which overlaps the part of the road section 189 of the main road M-16, from KM 22+546.50 to KM 35+427.66. The reconstruction of this section would increase level of service for road users.

Such development of road infrastructure in RS will contribute to significant investments in this part, so it will become one of the more competitive areas in the region of the Western Balkans. The development and construction of transport networks will significantly contribute to and influence the achievement of the goals of social, economic and overall functional development of the RS.

The main task of this multicriteria analysis is to evaluate all relevant criteria and to select the most suitable (appropriate) route. On the basis of a quantitative-qualitative analysis of various relevant characteristics of the variant solutions and the evaluation of the significance of these characteristics, the overall rating was done as well as the ranking of alignment variants. The assessment was done using the PROMETHEE method.

When selecting the criteria, the team took care to meet the economic, infrastructural and social goals of the project realization as well as environmental impact. Under the given circumstances, the criteria were chosen as to encompass and represent all relevant and available criteria that determine the main impacts.

In this context, 5 criteria groups were selected and further subdivided into 19 sub-criteria. Weighting values of individual criteria were calculated based on the significance and intensity of differences between individual criteria, as well as on the basis of previous research.

The individual evaluation of sub-criterion weight values was preceded by a joint consultation of the assessment team, which explained the multicriteria analysis procedure, presented the results of the variant analysis, and adopted the basic principles of weight assessment.

1.2. DESCRIPTION OF THE VARIANTS

Based on the analysis of planning documents of the republic and municipalities, as well as the analysis of spatial conditions with an emphasis on topographic, administrative, geo-political and economic conditions, the corridors of the future Krupa - Bočac route were selected.

The considered route is a result of the previous analysis and phases of the project. As a result of the previous phases of the project, variants 0, 3 and 4 are envisaged for further elaboration (Table 1).

Table 1. A comparative overview of the considered variants lengths

Variant	**Variant „V0“**	**Variant „V3“**	**Variant „V4“**
Length (m)	(L = 12,529 km)	(L = 12,505 km)	(L = 12,881 km)

VARIANT 0

The length of this Variant 0 is 12,529km. Variant 0 represents improvement of the existing road and have the same alignment as old road. This is completely suburban route.

VARIANT 3

The length of this Variant 3 is 12,504km which starts at KM 22+546.50 and ends at KM 35+051.31. This is completely suburban route.

The route of Variant 3 could be divided in three logical part in accordance of the type of intervention. First part is reconstruction of the existing main road through the settlement Krupa. This part is 3059.37 m long. The second part is completely new road by the river bed (on the right side of the river Vrbas). The length of this part is 5895 m. And finally, the third part represents the existing main road in length of 3550.44 m. For this part the route the reconstruction is predicted.

The route of the variant 3 is designed with the certain number of horizontal curves which are equal or bigger than predicted within ToR. The value of the grades is in the range between 0.5 and 1.5%.

VARIANT 4

The Variant 4 represents the route of the suburban road that passes by the settlements: Krmine, Agino Selo and Bočac. The length of this section is 12 881.16 m. The route starts at the station: KM 22 + 546.50, and ends at the station: KM 35 + 427.66. The major part of the terrain in which the route extends is hilly. The degree of restriction is significant and it is equal III. In accordance with the calculation speed (Vr=70km/h), the boundary elements are chosen.

From Krupsko polje at the beginning of the section on the elevation of 205 m above sea level, the route climbs to the zone of Krmine settlement, on the elevation of 380 m above sea level. After that, the route continues along the plateau towards the settlement Agino Selo. On this part of the route elevation is between 430 m and 480 m above sea level. After the passing of Agino Selo, the route starts to descend towards Bočac and the existing bridge over the river Vrbas. On this point altitude is 230 m above sea level.

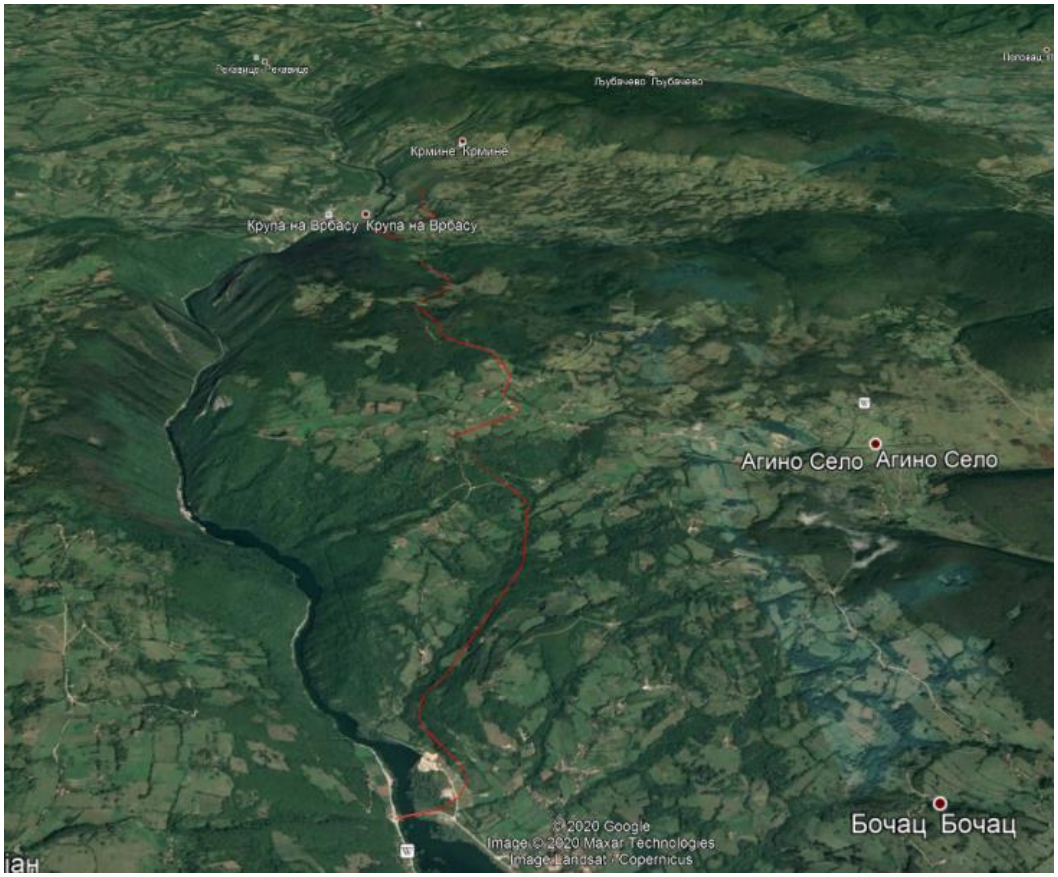

Figure 2. *Alignment of the route 2a variants*

2. METHODOLOGY

MCDA is often concerned with ranking a number of concrete alternatives from the best to the worst based on multiple criteria [1-2]. For example, Kuzovic et al. [3] applied the Multi-criteria analysis in evaluating of the road designs. Glavić et al. [4] used MCDA for cycling investment prioritization, while Milenkovic et al. [1] implemented MCDA for selecting the optimal road toll collection system.
The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method is one of the most recent (most current) MCDA methods developed by J.P. Brans in 1982 and further expanded (further upgraded) by Vincke and Brans [6]. PROMETHEE is an outranking method for a finite set of alternative actions (activities, procedures) that need to be ranked and selected among the criteria, which are often conflicting. PROMETHEE is also a fairly simple method of ranking in conception and application compared to other methods for multicriteria analysis [6].
The PROMETHEE family of methods, including PROMETHEE I for partial ranking of alternatives and PROMETHEE II for complete ranking of alternatives. The basic principle of PROMETHEE II is based on a comparison of pairs of alternatives for each selected criterion. The alternatives have been evaluated against different criteria, which must be maximised or minimised. The PROMETHEE II implementation requires two additional types of information: weighting coefficients and preference functions.
The procedure begins by determining the deviations based on pairwise comparisons (Equation 1). This is followed by the use of an appropriate preference function for each criterion in step 2 (Equation 2), the calculation of a general (comprehensive) preference index in step 3 (Equation 3), and the calculation of positive and negative flows (rankings) for each alternative, and a partial ranking in step 4 (Equation 4 and Equation 5). The process is completed by calculating the net flow (ranking) for each alternative and a complete ranking (Equation 6).
Step 1. Determining deviations (differences) based on pairwise comparisons

$$\boldsymbol{d_j(a,b) = g_j(a) - g_j(b)} \qquad (\mathbf{1})$$

Step 2. Application of preference function

$$\boldsymbol{P_j(a,b) = F_j\left[d_j(a,b)\right] \quad j = 1, \dots, k} \qquad (\mathbf{2})$$

Step 3. Computation of a general preference index

$$\forall\, \boldsymbol{a, b \in A}, \qquad \boldsymbol{\pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j} \qquad (\mathbf{3})$$

Step 4. Computation of flows/PROMETHEE 1 partial ranking.

$$\boldsymbol{\varphi^{+}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x)} \qquad (\mathbf{4})$$

$$\boldsymbol{\varphi^{-}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a)} \qquad (\mathbf{5})$$

Step 5. Computation of the total net flow /PROMETHEE II complete ranking

$$\boldsymbol{\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a)} \qquad (\mathbf{6})$$

2.1. DEFINITION OF LIST AND WEIGHTS OF CRITERIA'S

The MCDM analysis defined 19 indicators that are used to implement a procedure of selection of the planned Krupa – Bočac alternative routes. These 19 indicators were classified into the following 5 criteria groups.

1. Criteria group from the spatial and urbanistic aspect:
   (1) Characteristics of variants from the aspect of expropriation and demolition of buildings and other structures/facilities;
   (2) Characteristics of variants from the aspect of better traffic connection;
   (3) Characteristics of variants from the aspect of relation to urban agglomerations (centres, cities and settlements);
2. Criteria group from the aspect of environmental protection and preservation:
   (1) Characteristics of variants from the aspect of the impact of air pollution and noise emissions on the population;
   (2) Characteristics of variants with regard to usurpation of agricultural and forest areas;
   (3) Characteristics of variants with regard to the degradation of landscape, ambient and natural values;
3. Criteria group from the aspect of technical solutions:
   (1) Length of road (km);
   (2) Geological and hydrogeological conditions;
   (3) Total share of structures in the alignment;
   (4) Maximum slope of vertical alignment;
   (5) Curvature characteristic;
   (6) The complexity and duration of construction;
4. Characteristics from the traffic-exploitation aspect:
   (1) Level of Service;
   (2) Travel time;
   (3) Road safety;
5. Criteria group from the economic aspect:
   (1) Project implementation costs CapEx (€);
   (2) Vehicle operating costs (€);
   (3) Tunnel operating costs OpEx(€);
   (4) Maintenance costs RepEx (€);

For the determination of the criteria weights MDL (Modified Digital Logic) method is applied. MDL method is based on the pairwise criteria comparison [7]. Decision makers use a scoring scheme with values {1, 2 and 3} to represent less significant (1), equally significant (2), or more significant (3) criteria. After all, pairwise comparisons, MDL weights are calculated as follows:

$$w_j = \frac{\sum_{k=1}^{n} C_{jk}}{\sum_{j=1}^{n} \sum_{k=1}^{n} C_{jk}}, \quad j \text{ and } k = \{1, \dots, n\};\ j \neq k \qquad (7)$$

2.2. FORMATION OF A MATRIX WITH SCORING AND WEIGHTING OF THE CRITERIA, AND PREFERENCES

The scoring for all 19 indicators were quantified by using the existing documentation for a number of indicators, as well as by doing adequate calculations, analyses and experts' assessment for other indicators.
Formation of a matrix with scoring and weighting of the criteria, and preference functions was done in PROMETHEE business edition software and given in table below.

Table 2. Matrices with scoring and weighting of the criteria, and Preference functions by alternative road solutions

Evalu-ations	Min/ Max	Weight	Preference function	q	p	s	Variant 3	Variant 4	Variant 0
X11	min	4.00	V-shape	n/a	2.00	n/a	1.00	1.00	1.00
X12	max	4.00	V-shape	n/a	2.00	n/a	3.00	3.00	3.00
X13	max	4.00	V-shape	n/a	2.00	n/a	4.00	5.00	4.00
X21	min	4.00	V-shape	n/a	2.00	n/a	4.00	3.00	3.00
X22	min	4.00	V-shape	n/a	2.00	n/a	1.00	3.00	1.00
X23	min	5.00	V-shape	n/a	2.00	n/a	3.00	3.00	1.00
X31	min	6.00	V-shape	n/a	0.20	n/a	12.51	12.88	12.53
X32	max	4.00	V-shape	n/a	2.00	n/a	1.00	3.00	5.00
X33	min	4.00	V-shape	n/a	5.00	n/a	10.20	0.46	0.00
X34	min	4.00	V-shape	n/a	4.00	n/a	1.60	7.00	1.50
X35	min	4.00	V-shape	n/a	5.00	n/a	123.20	120.20	142.98
X36	min	5.00	V-shape	n/a	2.00	n/a	5.00	3.00	1.00
X41	max	5.00	V-shape	n/a	2.00	n/a	3.00	4.00	3.00
X42	min	5.00	V-shape	n/a	2.00	n/a	0.17	0.16	0.17
X43	max	7.00	V-shape	n/a	2.00	n/a	3.00	4.00	3.00
X51	min	8.00	V-shape	n/a	1000000	n/a	23400000	14014000	5530000
X52	min	7.00	V-shape	n/a	0.01	n/a	1.00	1.04	1.00
X53	min	7.00	V-shape	n/a	2.00	n/a	5.00	0.00	0.00
X54	min	7.00	V-shape	n/a	0.01	n/a	1.00	1.03	1.00

3. MCDM ANALYSIS RESULTS

3.1. PROMETHEE I AND II RANKING

There are two PROMETHEE rankings based on the calculation of preferential flows that are based on the calculation of preferential flows:

- PROMETHEE I Partial ranking
- PROMETHEE II Complete ranking

PROMETHEE II complete ranking means that all alternatives were compared and that ranking does not include a possibility of non-comparison when comparison is difficult. The result of ranking thus can be questionable, especially in the presence of strong conflicting criteria. Ranking is based on the net preferential flow. It combines two other preferential flows into one in the summary result. Thus, the alternative a has an advantage over the alternative b in PROMETHEE II ranking if and only if the advantage over b is based on the net preferential flow. In this specific case it is:

$$\boldsymbol{aP^{II}b} \textbf{ if and only if } \boldsymbol{\Phi(a) > \Phi(b)}$$

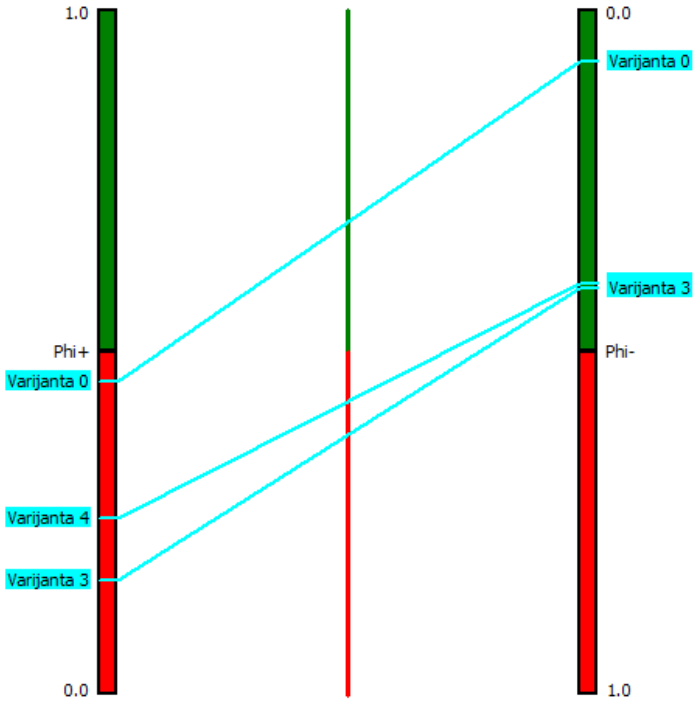

Figure 3. *PROMETHEE I and II ranking*

Based on the PROMETHEE I ranking given in figure 3 we can see that **Variant 0** is having advantage over variants C3 and V4 by both positive and negative flow.
Based on the PROMETHEE II ranking given in figure 3 we can see that **Variant 0** is the first ranked by the net flow.
PROMETHEE Table shows Phi, Phi+ and Phi- results. Alternatives are ranked according to the PROMETHEE II complete ranking.

Table 3. Ranking of alternatives by applying the Promethee model

Rank	Alternative	**Phi**	**Phi +**	**Phi-**
1	Variant 0	0.3812	0.4565	0.0753
2	Variant 4	-0.1423	0.2575	0.3998
3	Variant 3	-0.2389	0.1669	0.4058

According to the previously presented PROMETHEE rankings (Figure 3), as well as Table 3, the compromise ranking of variants for route 2a on the Krupa Bočac section is:

- Variant 0
- Variant 4
- Variant 3

3.2. SENSITIVITY ANALYSIS

Sensitivity analysis was conducted to see the stability of the results, and to give all the answers to possible variations of the individual weights of the criteria in the range from 0% to 100%, relative to the weights determined in this study.
In the graphs below, the horizontal dimension corresponds to the weight of the selected criterion, and the vertical dimension corresponds to Phi net flow. For each alternative, the line is drawn to show net flow as a function of the criterion weight. On the left and right edges of the figure, the criterion weight is 0% and 100%, respectively, and the alternatives are ranked according to that one criterion.
The position of the vertical green and red lines corresponds to the current weight of the criteria. The section of the action lines with the vertical line gives PROMETHEE II complete ranking. Two dashed vertical lines show the weight interval in which PROMETHEE II complete ranking remains unchanged (WSI - weight stability interval).
The figures below show a sensitivity analysis using stability intervals for all criteria.

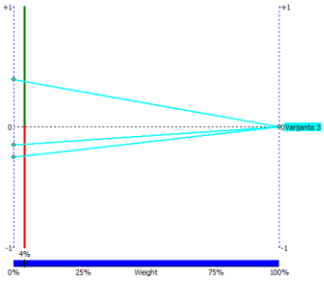

Figure 4. *Sensitivity analysis for criteria expropriation and demolition of buildings and other structures/facilities*

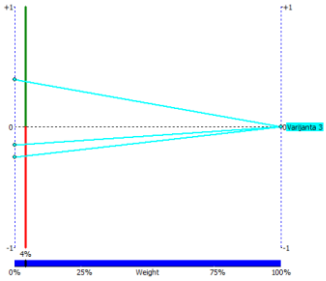

Figure 5*. Sensitivity analysis for criteria better traffic connection*

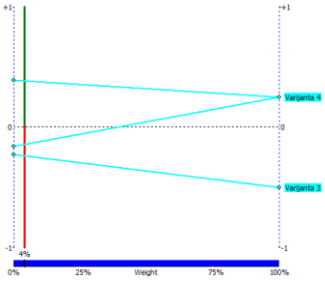

Figure 6. *Sensitivity analysis for criteria relation to urban agglomerations (centres, cities and settlements)*

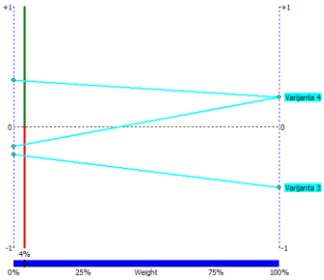

Figure 7. *Sensitivity analysis for criteria impact of air pollution and noise emissions on the population*

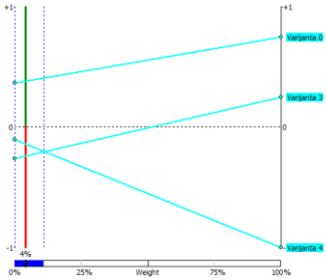

Figure 8. *Sensitivity analysis for criteria usurpation of agricultural and forest areas*

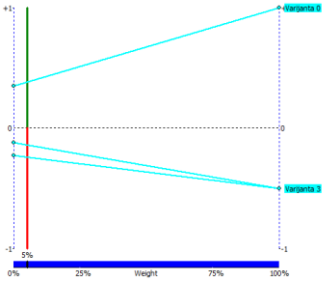

Figure 9. *Sensitivity analysis for criteria degradation of landscape, ambient and natural values*

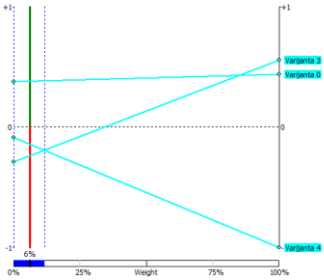

Figure 10. *Sensitivity analysis for criteria road length*

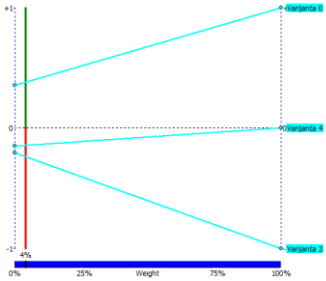

Figure 11. *Sensitivity analysis for criteria geological and hydrogeological conditions*

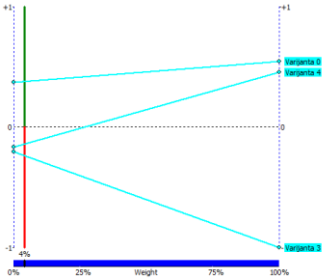

Figure 12. *Sensitivity analysis for criteria total share of structures in the alignment*

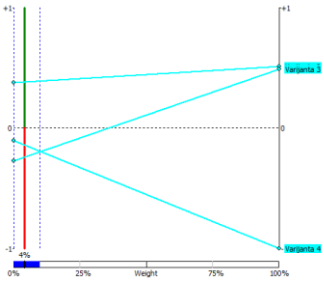

Figure 1. *Sensitivity analysis for criteria maximum slope of vertical alignment*

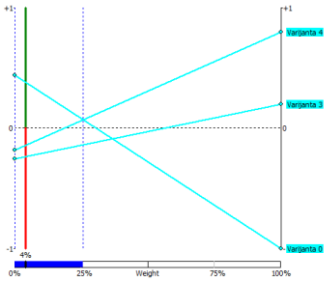

Figure 14. *Sensitivity analysis for criteria curvature characteristics*

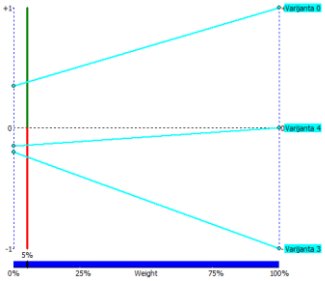

Figure 15. *Sensitivity analysis for criteria complexity and duration of construction*

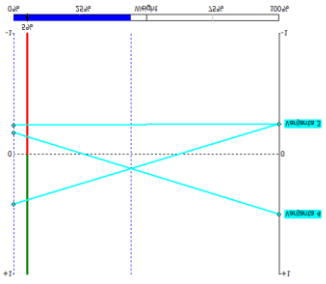

Figure 2. *Sensitivity analysis for criteria level of service*

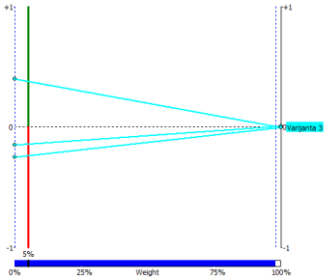

Figure 3. *Sensitivity analysis for criteria travel time*

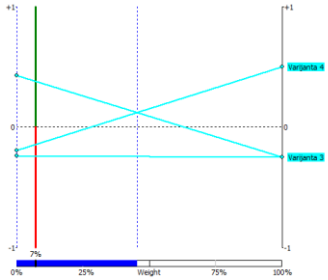

Figure 4. *Sensitivity analysis for criteria traffic safety*

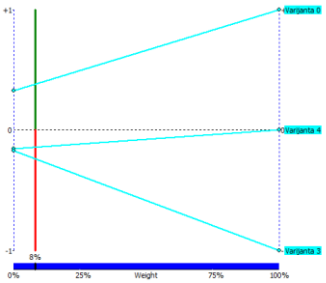

Figure 19. *Sensitivity analysis for criteria project implementation costs*

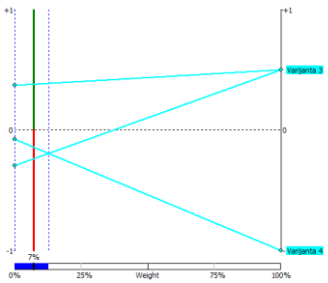

Figure 20. *Sensitivity analysis for criteria vehicle operating costs*

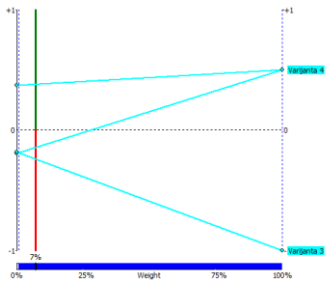

Figure 21. *Sensitivity analysis for criteria tunnel operating costs*

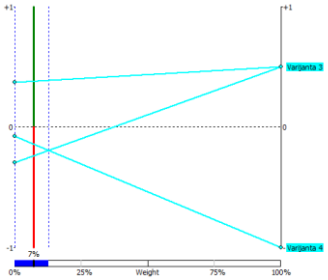

Figure 22. *Sensitivity analysis for criteria maintenance costs*

Sensitivity analysis presented on Figure 4 to 22 leads to a conclusion that the first ranked varinat has very prominent stability according to all criteria, and one can conclude that the ranking is stable by most criteria.

4. DISCUSSION AND CONCLUSION

The previously performed analysis includes a detailed comparative analysis of all parameters that have an impact on the proposed alignment of route 2a on the section Krupa-Bočac. Based on the MCDM analysis using the PROMETHEE method according to the given list and weight of criteria, it can be concluded that variant 0 of the Krupa - Bočac section is the compromise first ranked variant.

If we analyse preferential flows Phi, Phi+ and Phi we can conclude that variant 0 is best solution according to all 3 flows, while variants 3 and 4 have negative Phi net flow and both V3 and V4 variants represent two least bad solutions. The main disadvantage of variant V3 is the high construction costs. The disadvantage of variant 4 is the high longitudinal grade.

Sensitivity analysis has shown that the first place has very prominent stability according to most criteria and that the first place is stable by most criteria. However, it is important to point out that the proposed compromise solution is based on defined weights of criteria. In other words, if there are significant changes in some criteria weights, there may be changes in the ranking.

Decision support framework presented in this paper can help future researchers and decision makers in solving similar problems of road alignment selection.

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