MULTI-CRITERIA ANALYSIS OF VARIATION SOLUTIONS FOR THE PIPELINE ROUTE BY APPLYING THE PROMETHEE METHOD

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Preliminary notes

The paper considers the problem of selecting the most appropriate variation for the pipeline route Beloševac - Divci within the Kolubara regional water supply system (Serbia). Variations are evaluated according to five criteria, three of which have an economic character. The problem of selecting the optimal variant for the pipeline route is solved using the multi-criteria analysis by applying the PROMETHEE method and the implementation into the software package Visual PROMETHEE 1.4. The PROMETHEE method has proved to be applicable and suitable in solving practical problems related to civil engineering, in the phase of the final decision-making in the area of construction planning. The application of multi-criteria evaluation methodology, provided in this paper, proposes the variant with the minimal construction costs.

Keywords: criteria; multi-criteria analysis; pipeline routes; PROMETHEE method; variations

Višekriterijska analiza varijantnih rješenja trase cjevovoda primjenom metode PROMETHEE

Prethodno priopćenje

U radu je razmatran problem izbora najpovoljnije varijante trase cjevovoda Beloševac - Divci u okviru Kolubarskog regionalnog sustava vodosnabdjevanja (Srbija). Varijante su vrednovane na osnovu pet kriterija, od kojih su tri kriterija ekonomskog karaktera. Problem izbora optimalne varijante trase cjevovoda riješen je višekriterijskom analizom primjenom metode PROMETHEE implementacijom u softversko rješenje Visual PROMETHEE1.4. Metoda PROMETHEE se pokazala primjenjivom i pogodnom u praktičnim problemima građevinskog inženjerstva, u fazi konačnog odlučivanja u području planiranja izgradnje. Primjenom metodologije višekriterijskog vrednovanja, danom u ovom radu, korisniku se predlaže varijanta s minimalnim troškovima izgradnje.

Ključne riječi: kriteriji; metoda PROMETHEE; trase cjevovoda; varijante; višekriterijska analiza

1 Introduction

System optimization in construction is a complex process enclosing both theoretical and practical knowledge of experts from diverse disciplines. As provided in [1], in order to incorporate all or the most significant factors influencing the optimization solution, it is necessary to include several criteria into the optimization procedure. The final objective of optimization is to provide qualitative and timely decisions based on diverse models and to provide aid in the selection of the best alternative, i.e. solution. Problems in construction are mainly poorly structured in the mathematical sense; hence, it is necessary to apply adequate methods based on the expert knowledge of decision makers while solving them. The role of the decision maker is primarily observed in recognizing these problems, yet also in leading these problems to the level when they can be solved using mathematical models [1].

With the construction planning problems, the selection of the most adequate variant in the multi-criteria analysis implies the analysis with more perspectives (economic, technological, technical, environmental, etc.). The problem where there are more alternatives (variations) and more criteria, and where some of them need to be maximized while some to be minimized, demands for the application of methods that are more flexible in comparison to the mathematical techniques of pure optimization. The obtained solutions in those cases most commonly present the compromise [2], i.e. the best solutions in accordance with the defined optimization criteria and objectives.

The paper presents the multi-criteria analysis of the variations for building the pipeline section Beloševac - Divci, within the Kolubara regional water supply system.

Variants are evaluated according to five criteria, where three are quantitative and economic – material cost, machinery and labour cost, and utilities cost, while other two are qualitative criteria – ecological factor and degree of feasibility. To select the most suitable variation, the PROMETHEE method has been used in both variations for partial and complete ranking. The method PROMETHEE (**P**reference **R**anking **O**rganization **M**ethod for **E**nrichment **E**valuations) belongs to the group of methods for multi-criteria decision-making within the alternatives described with more attributes. Jean-Pierre Brans developed and presented the method in 1982 [3] and further in other papers from 1984 [4] and 1985 [5].

In order to speed and simplify the decision-making process, diverse information systems, programs and tools can be applied in the optimization process. For the demands of the analysis in this paper, the application Visual PROMETHEE 1.4 [6] is used. Visual PROMETHEE software provides a significant support in the situations when the decision-making criteria are in conflict. The application of this software provides information on the advantages and drawbacks of one solution in relation to another. The advantage of the software is in the fact that it provides an opportunity for more diverse analyses which in turn provide the decision maker to reach the most adequate solution faster, simpler and more efficient.

2 Literature review

Behzadian et al. [7] made a comprehensive literature review on the PROMETHEE methodologies and applications. They made a reference bank and included 217 papers published in 100 scholarly journals since 1985.

Within the construction industry, Jato-Espino et al. in [8] reviewed the application of 22 different methods belonging to the multi-criteria decision discipline in various areas of the construction industry clustered in 11 categories. They argue that the application of the PROMETHEE method is significant in construction, yet its tendency to dilute the explicitness of the results when the number of criteria is large limits its usage.

Gervasio and da Silva in [9] have presented a new approach in the decision-making process by applying the PROMETHEE and AHP in a case study: the comparative assessment of alternative bridges taking into account the environmental, economic and social criteria evaluated over the complete life-cycle of the bridges. San Cristobal [10] analyses the usage of the PROMETHEE method in fuzzy environments in order to determine the critical path of a network, considering not only time but also cost, quality, and safety criteria, and concluding that there are benefits in the application of the method in comparison to the dominant application of the PERT method for this type of problems.

Jajac et al. [11] form the model for support in infrastructure maintenance in urban areas based on the PROMETHEE method and provide the example of the city of Split, Croatia. Furthermore, Jajac et al. [12] use the PROMETHEE method for the selection of the optimal site locations within the investment planning, based on 13 criteria.

Yilmaz and Dagdeviren [13] and Phogat and Singh [14] use the PROMETHEE method for the selection of equipment, with the former analysing a production company and the latter analysing the application of the five multi-criteria decision making (MCDM) techniques to a typical selection of equipment used for hilly road construction, using the PROMETHEE method as one of the possibilities.

In the Republic of Serbia, Bajcetic et al. [15] perform the selection of the optimal reconstruction of the regional water supply system, while Markovic et al. [16] select the most suitable variation for the highway E-763 entering the city of Belgrade, Serbia, utilizing the PROMETHEE method.

3 Methodology for the multi-criteria analysis for the pipeline route

One of the most significant and largest infrastructural projects in Serbia, the Kolubara regional water supply system, includes the territories of the city of Valjevo and the municipalities of Lajkovac, Ub and Mionica, as well as the Belgrade municipality Lazarevac. It is designed in a manner that the supply of water for those territories will come from the accumulation Stubo-Rovni on the river Jablanica and other available local drinking water springs on the territory included in the plan. The project includes the completion of the dam Rovni and the creation of the water accumulation of the basin surface of 104 m^2 and the volume of approximately 50 million m^3 water, together with the construction of approximately 40 km of water network with all accompanying facilities – reservoirs, pump stations, collector chambers, water treatment plants, etc.

3.1 Problem description

The methodology of the multi-criteria evaluation and the selection of the most appropriate variant for the pipeline route is presented for the section Beloševac - Divci (Fig. 1) [17]. The section Beloševac - Divci extends from the manhole of the section shutter in the village Beloševac at the location km 3 + 029,07 to the manhole of the measuring block in the village Divci at the location km 13+368,72. With the length of approximately 10,4 km, it represents the longest section on the entire project of the Kolubara regional water supply system. The route is placed outside the city core of Valjevo, and it runs through the valley of the river Kolubara from the south side of the railway route Beograd - Bar and the highway M26.
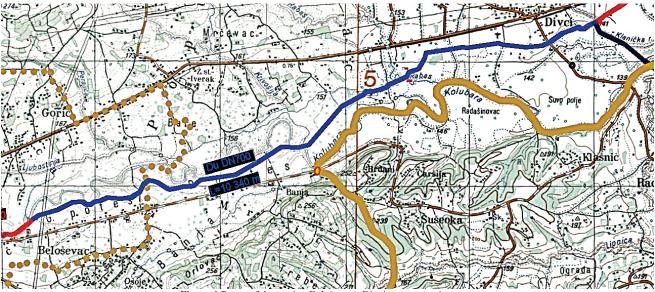

Figure 1 Route of the section Beloševac - Divci on an overview map

The pipeline is designed from the steel pipes with the diameter of 700 mm. At the location km 9+640,42 there is a measuring block and the routes for the local villages Bela Stena and Lukavac. Up to that point, the pipeline is dimensioned for the pressure of 10 bar (PN10), while after the measuring block till the end of the section it is designed for the nominal pressure of 16 bar (PN16). The nominal pressure also conditions the pipe wall thickness, so at the section DN700 PN10 the pipes $\varnothing 711,2 \times 7,1$ mm will be constructed, while at the section DN700 PN16 the pipes $\varnothing 711,2 \times 9,0$ mm will be used.

There is the overall number of 26 manholes situated on the route, where there are 11 air valve ones and 11 tap holes, 2 measuring block manholes with tap holes and 2 section shutter manholes. Some of the manholes contain equipment that unifies the purpose of different types of manholes. On the route, there are also 4 passes under the river and the pipeline route under the highway.

During the design process, there have been considerations related to the fact that the route should cross public areas or the areas owned by the Republic of Serbia or public institutions; however, since the first project was completed in 1980s, the ownership structure has been altered, leading to the change of the route in

these sections and opening a problem of selecting the most optimal pipeline route variant.

The multi-criteria optimization implies the definition of the evaluation criteria, variant selection, adequate method application and the selection of the best solution (optimal solution).

3.2 Analysis criteria

The optimization is based on five criteria with the objective of cost minimization for pipeline construction. In the proposed analysis criteria, first three criteria are related to expenses, they are quantitative and expressed in money units (€), while the fourth and the fifth criteria are qualitative and obtained as a grade in the range from 1 to 10. The problem of multi-criteria decision-making is presented in Fig. 2.The description of the optimization criteria is presented in Tab. 1.

In accordance with the objective of the optimization, which is to minimize costs, in the proposed optimization models the qualitative criteria (*EF* and *SI*) have a diminished significance by attributing them the weight coefficient 0,3.
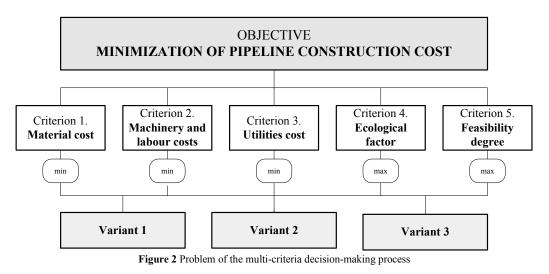

Figure 2 Problem of the multi-criteria decision-making process

Table 1 Optimization criteria

Criterion	Criteria description
Material cost *TM*	This criterion includes the price for all necessary materials – pipes, type pieces, framework, fuel, etc.
Machinery and labour costs *TR*	It includes the expenses for construction machinery, which are dominant, and the expenses of the labour employed at the site. The duration of works, efficiency, as well as the number of labour and their qualifications directly influence the labour costs.
Utilities cost *RT*	Utilities costs imply additional expenses related to – land, accommodation, fees and taxes for diverse institutions, penalties, etc. This criterion also includes a part of the expenses for follow-up jobs.
Ecological factor *EF*	Ecological factor is the indicator of the influence of the building process onto the environment. In the evaluation of variants, it is presented with grades in the range from 1 to 10 according to Tab. 2, and in accordance with the number of grown trees over 15 m high that are to be removed from the pipeline route.
Feasibility degree *SI*	The degree of feasibility presents the level of complexity of the coordination of works determined on the basis of terrain configuration and vegetation conditions, as well as organization problems of the contractor on a given location in the sense of the situation with the available equipment, degree of efficiency of the mechanization operators, and the quality of available managing structures. The variant is provided with the grades in the range from 1 to 10 in accordance with the distribution as presented in Tab. 3.

Table 2 Ecological factor

EF									
Number of trees (trees over 15 m high) that has to be removed from the pipeline construction route									
0÷5	5÷10	10÷15	15÷20	20÷25	25÷30	30÷35	35÷40	40÷45	over 45
Points									
10	9	8	7	6	5	4	3	2	1

Table 3 Feasibility degree (SI)

Job conditions		Organizational conditions				
		Excellent equipment conditions and skills of workforce and excellent planning supervision and coordination of work	Excellent equipment conditions and skills of workforce and average planning supervision and coordination of work	Average equipment conditions and skills of workforce and average planning supervision and coordination of work	Average equipment conditions and skills of workforce and poor planning supervision and coordination of work	Poor equipment conditions and skills of workforce and poor planning supervision and coordination of work
		Excellent	Very good	Good	Poor	Very poor
Plains with low vegetation	Excellent	10	9	8	7	6
Plains with dense vegetation	Very good	9	8	7	6	5
Hills with low vegetation	Good	8	7	6	5	4
Hills with dense vegetation	Average	7	6	5	4	3
Mountains with low vegetation	Poor	6	5	4	3	2
Mountains with dense vegetation	Very poor	5	4	3	2	1

3.3 Variant solutions

Prior to generating possible variant solutions, the analyses have been performed on the location conditions (geological and hydrological soil properties), selection of mechanization, and primarily, on considering the fact for the pipeline routes to pass as little as possible over the cultivated land and land in private property, in order to reduce the construction costs even in this optimization phase. On the route Beloševac - Divci, the evaluation is conducted on variation solutions within six variants (Tabs. 4, 5, 6, 7 and 8). The second variant is described in detail in the multi-criteria decision-making procedure (Section 4).

Table 4 FIRST VARIATION – variants

Variant 1	The original solution of the route is placed between the location km 3+196,82 and km 4+085,36 in the length of 888,53 m. In this section of the route, there are 5 curves and another turn that is to be constructed without the curve, one type air valve chamber and one type mud tap hole. The pipeline runs under the road surface in one section, between the locations km 4+001,84 and km 4+054.76 in the length 52,92 m. It is a rural road, an earth road, yet after covering the pipeline it is necessary to macadamize the road.
Variant 2	In an alternative solution, the route stretches between the location km 3+196,82 and km 4+070,66, with the total length of 873,84 m. Therefore, the route is shorter in this variant. It is necessary to construct 4 curves and one turn. At T182 the turn has a small angle, and can thus be constructed without the curve. The number of chambers/manholes is the same in both variants.

Table 5 THIRD VARIATION – variants

Variant 1	This variant is situated between the locations km 5+349,24 and km 5+608,04, having the length of 258,80 m. Three turns will be constructed with curves. There are neither chambers nor additional materials necessary.
Variant 2	Stretching between the locations km 5+349,24 and km 5+649,30, the second variant has the length of 300,06 m. 4 curves are necessary. This variant does not have any proposed chambers.
Variant 3	The third variant lies between the locations km 5+349,24 and km 5+646,33, with the length of 297,09 m. It is necessary to construct 3 curves and there are no proposed chambers.

Table 6 FOURTH VARIATION – variants

Variant 1	The length of the section is 821,34 m and it is situated between the locations km 8+819,09 and km 9+640,42. In this section, there is one type air valve chamber. Out of 6 turns of the pipeline, 4 will be constructed with curves.
Variant 2	The route lies between the location km 8+819,09 and km 9+713,31, with the length of 894,22 m. With the alteration of the terrain, the pipeline cross-section profile is altered; hence the new solution states that it is necessary to construct two additional chambers, one type mud tap hole and one air valve chamber. All three turns of the pipeline are to be curved.

Table 7 FIFTH VARIATION – variants

Variant 1	Stretches between the locations km 9+995,48 and km 10+547,32 with the length of 551,84 m. The ownership structure and the land boundaries have been altered since the Main project; therefore, the route rambles through a great number of land parcels. In this route there are 5 curved turns and one air valve chamber.
Variant 2	The route of the second variant is situated between the locations km 9+995,48 and km 10+539,33 and it is 543,85 m long. The second variant shares the beginning of the route with the first variant, and they separate in order to avoid the wood and high trees. This variant passes through smaller number of land parcels and has one chamber less in relation to the first variant.
Variant 3	The third variant is 583,90 m long and it is the longest of the three proposed variants, placed between the locations km 9+995,48 and km 10+579,38. It is designed in a manner to pass the least number of land parcels and to have the least number of curves (total of 3). In this route, there is one type air valve chamber.

Table 8 SIXTH VARIATION – variants

Variant 1 According to the Main project, this route section is situated between the locations km 12+938,34 and km 13+344,96 with the length of 406,62 m. In this section there are no chambers, and there are four curved turns.
Variant 2 The second variant begins with the location km 12+938,34 and ends at km 13+329,96. Its length is 391,62 m. In this section there are no chambers, while the curves are constructed in three locations.
Variant 3 The third variant stretches from the location km 12+938,34 and it ends at km 13+329,11. It is 390,77 m long. Same as with the previous two variants, there are no proposed chambers, and there are 3 curves to be constructed.

3.4 Optimization method

The method relies on the evaluation of alternatives according to the criteria and the determination of the measure of mutual domination of alternatives used to rank them. The PROMETHEE method uses preference functions presented in Tab. 9 for mutual alternative comparison. There are six standard types of these functions. The selection of the preference function and the definition of parameters in them are performed by the method user, most commonly the decision maker or the analyst.

Table 9 Preference functions in the method PROMETHEE

GRAPH	DEFINITION	CRITERION
	$H(d) = \begin{cases} 0 \text{ if } d = 0 \\ 1 \text{ if } |d| > 0 \end{cases}$	**Type I: Usual criterion** (regular; no parameters; rarely used)
	$H(d) = \begin{cases} 0 \text{ if } |d| \leq q \\ 1 \text{ if } |d| > q \end{cases}$	**Type II: Quasi criterion** (contains only the indifference threshold q; more often used with the evaluation of alternatives for qualitative criteria)
	$H(d) = \begin{cases} \dfrac{|d|}{p} \text{ if } |d| \leq p \\ 1 \text{ if } |d| > p \end{cases}$	**Type III: Criterion with linear preference** (contains only the preference significance threshold p; commonly used with the evaluation of alternatives for qualitative criteria; different from the previous one since H(d) is proportional to the alternative deviation in the value range from 0 to |p|)
	$H(d) = \begin{cases} 0 \text{ if } |d| \leq q \\ 1/2 \text{ if } q < |d| \leq p \\ 1 \text{ if } |d| > q \end{cases}$	**Type IV: Level criterion** (contains the indifference threshold q and preference significance threshold p; H(d) is step-shaped and it is often used with the evaluation of alternatives for qualitative criteria)
	$H(d) = \begin{cases} 0 \text{ if } |d| \leq q \\ \dfrac{|d| - q}{p - q} \text{ if } q < |d| \leq p \\ 1 \text{ if } |d| > q \end{cases}$	**Type V: Criterion of linear preference with indifference area** (contains the indifference threshold q and preference significance threshold p; H(d) is proportional to the alternative deviation in the range from (-p-q) to (+q+p); it is often used with the evaluation of alternatives for quantitative criteria)
	$H(d) = 1 - e^{\frac{-d^2}{2\sigma^2}}$	**Type VI: Gaussian criterion** (contains only the Gaussian significance threshold σ; rarely used)

The mutual comparison of the pairs of alternatives in relation to the set criterion is used to define the intensity of difference between two alternatives $P(a, b)$ (Tab. 9). The function moves between 0 and 1, with the following meaning: if $P(a, b) = 0$, there is no difference between alternatives; if $P(a, b) = 1$, the alternative a completely dominates over the alternative b. The evaluation and ranking of alternatives implies the determination of d's and the corresponding values of H's for the selected functions from Tab. 1. Namely, for every criterion, one has to select a function H, and then perform the comparison of alternatives for that criterion. All criteria have to be completed, the sums of H values have to be determined in comparison to every criterion and finally the so-called partial and total preference indices for alternatives have to be determined.

The PROMETHEE method comprises three basic steps:
– Preference modelling
– Aggregation
– Exploitation

Visual PROMETHEE software exploits solutions on two levels:
– Partial exploitation PROMETHEE I – it is based on the calculation of priority flows $Phi +$ and $Phi -$. The problem occurs in the inability of contact between actions in the case when the preference flows $Phi +$ and $Phi -$ provide conflict rankings.
– Complete exploitation PROMETHEE II – based on the net preference flow Phi.

The method PROMETHEE is designed in a manner that there is no implied method of problem solving;

rather, the process itself has to be modelled from one case to another and it is unique for every analysis. The implementation of calculated criteria values into the software Visual PROMETHEE provides the possibility of result analysis before reaching the final decision on the optimal solution.

4 Evaluation of the variants in the second variation for the pipeline route and the selection of the optimal variant

Multi-criteria analysis (evaluation, modelling, the application of the PROMETHEE method, and the selection of the optimal variant) is presented in detail for the second variation of the pipeline route Beloševac - Divci. The second variation begins at the location km 4+443,10 on the segment of the route PN10 (Fig. 3). In construction, the pipes ⌀711,2 × 7,1 mm are used. Two

proposed variants are being analysed and the optimal variant is being selected according to the point of construction costs minimization.

Variant 1 – According to the Main project, the original route solution is situated between the locations km 4+443,10 and km 4+993,79 in the length of 550,69 m. The pipeline is placed under the road that is privately owned. It is a macadam road and the route passes through it in the length of approximately 400 m. In this section, the road is necessary to be macadamized after covering the pipeline. Next to the road, there are two oak trees over 15m high, which have to be removed. After the point T87 the route moves to the public road surface and the variant ends there. In this section, there are 4 curves and another 3 turns constructed without curves. On the route, there is one type air valve chamber and one type mud tap hole.
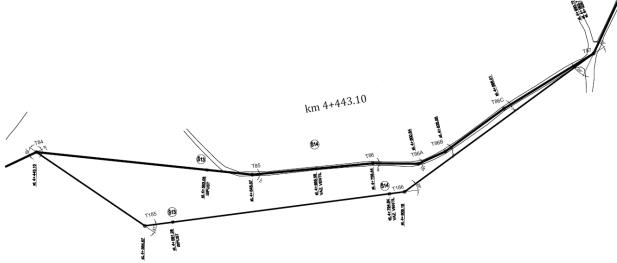

Figure 3. Situation overview of the second variation

The route passes through the cultivated land, and under the road afterwards, so the minimum of vegetation is removed except for the two high oak trees. This variant received the ecological factor grade 10 according to Tab. 2. In this variant, it is determined that there are excellent equipment conditions and skills of workforce, as well as

average planning supervision and coordination of work; it is also a plain terrain with low vegetation, hence the degree of feasibility is graded as 9.

Numerical values for all criteria, for the first variant of the pipeline construction, are provided in Tab. 10.

Table 10 Optimization criteria – Variant 1

Criterion/variant	Material cost TM (€)	Machinery and labour costs TR (€)	Utilities cost RT (€)	Ecological factor EF	Feasibility degree SI
Variant 1.	227 479,82	14 075,59	89 574,00	10	9

Variant 2 – In the second variant, the road is situated almost parallel to the already designed route, yet outside the road surface in order to avoid the road that is in the public ownership. In this case, it is necessary to pass through one land parcel wooded with broadleaved trees, and further through the cultivated land. The route is situated between the locations km 4+443,10 and km 5+026,65, with the total length of 583,55 m, which is longer than the original solution. The route has 4 pipeline curved turns and the same number of chambers as in the first variant.

At the beginning of the route, the pipeline passes through the land parcel wooded with poplars and oaks in

the length of approximately 125 m. In this area, around 30 high trees should be removed. In this section, the land is treated as uncultivated, yet it is necessary to pay compensation for the cut trees. In the remaining of the route, the pipeline passes through the cultivated land in the plain area, with the exception of the very end of the route in this variant, where the pipeline ends on a private road in the length of approximately 20 m.

The unfavourable impact of the construction process of this variant of the pipeline route onto the environment, including the removal of a relatively large number of healthy trees, provides this variant with the eco factor grade 5, in accordance with Tab. 2. It is only necessary to

engage a group of labourers that will cut the trees and clean the route, and gather the trunks in a close proximity since they are to remain in the property of the land owner and hence their transport is not required. Likewise, it is determined for this variant as well that there are excellent equipment conditions and skills of workforce, as well as

average planning supervision and coordination of work, and that the area is a plain with low vegetation; hence, the degree of feasibility is 9.

Numerical values of the criteria functions for the second variant of the pipeline construction are provided in Tab. 11.

Table 11 Optimization criteria – Variant 2

Criterion/variant	Material cost TM (€)	Machinery and labour costs TR (€)	Utilities cost RT (€)	Ecological factor EF	Feasibility degree SI
Variant 2.	240 231,31	14 596,58	62 173,30	5	9

Second variation	Mater. cost	Mach. lab.	Utilities cost	Ecolog. fac.	Feasib. deg.
Unit	Eur	Eur	Eur	koef	koef
Cluster/Group	◆	◆	◆	◆	◆
Preferences					
Min/Max	min	min	min	max	max
Weight	27,78	27,78	27,78	8,33	8,33
Preference Fn.	Usual	Usual	Usual	V-shape	V-shape
Thresholds	absolute	absolute	absolute	percentage	percentage
- Q: Indifference	n/a	n/a	n/a	n/a	n/a
- P: Preference	n/a	n/a	n/a	10	10
- S: Gaussian	n/a	n/a	n/a	n/a	n/a
Statistics					
Minimum	€ 227.479,82	€ 14.075,59	€ 62.173,30	5,00	9,00
Maximum	€ 240.231,31	€ 14.596,58	€ 89.574,00	10,00	9,00
Average	€ 233.855,57	€ 14.336,08	€ 75.873,65	7,50	9,00
Standard Dev.	€ 6.375,75	€ 260,50	€ 13.700,35	2,50	0,00
Evaluations					
Variant 1. ◇	€ 227.479,82	€ 14.075,59	€ 89.574,00	10,00	9,00
Variant 2. ◆	€ 240.231,31	€ 14.596,58	€ 62.173,30	5,00	9,00

Figure 4 Model A – main window of the Visual PROMETHEE software

Second variation	Mater. cost	Mach. lab.	Utilities cost	Ecolog. fac.	Feasib. deg.
Unit	Eur	Eur	Eur	koef	koef
Cluster/Group	◆	◆	◆	◆	◆
Preferences					
Min/Max	min	min	min	max	max
Weight	27,78	27,78	27,78	8,33	8,33
Preference Fn.	Linear	Linear	Linear	V-shape	V-shape
Thresholds	absolute	absolute	absolute	percentage	percentage
- Q: Indifference	€ 0,00	€ 0,00	€ 0,00	n/a	n/a
- P: Preference	€ 27.400,70	€ 27.400,70	€ 27.400,70	10	10
- S: Gaussian	n/a	n/a	n/a	n/a	n/a
Statistics					
Minimum	€ 227.479,82	€ 14.075,59	€ 62.173,30	5,00	9,00
Maximum	€ 240.231,31	€ 14.596,58	€ 89.574,00	10,00	9,00
Average	€ 233.855,57	€ 14.336,08	€ 75.873,65	7,50	9,00
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Evaluations					
Variant 1. ◇	€ 227.479,82	€ 14.075,59	€ 89.574,00	10,00	9,00
Variant 2. ◆	€ 240.231,31	€ 14.596,58	€ 62.173,30	5,00	9,00

Figure 5 Model B – main window of the Visual PROMETHEE software

4.1 Analysis of the variant solutions of the second variation – OPTIMIZATION MODELS

MODEL A – In the model A, the quantitative criteria (first three criteria) are modelled using the regular preference function (*Usual*), while the qualitative criteria (fourth and fifth criteria) using the preference function (*V-Shape*), with the preference significance threshold $p = 10$. The values of the weight coefficient are presented in percentage and in total they are 100 %. After the input of all values into the Visual PROMETHEE software, the output results of the partial (PROMETHEE I) and global ranking (PROMETHEE II) are obtained. The overview of the main window (MODEL A) is provided in Fig. 4.

The ranking is conducted in a manner that the greatest preference (*Phi*) is possible to be obtained as +1, while the lowest preference is −1. The most suitable (optimal) solution is, therefore, the one that obtains the overall performance +1, i.e. the preference as close as possible to this value. Output ranking results are presented in Fig. 6.

MODEL B – In the second one the optimization model B, for the first three criteria related to costs, instead of the regular (*Usual*) function, the linear preference function is selected, with the preference significance threshold p being the double maximal standard deviation. The function of the preference of qualitative criteria remains unaltered as in the model A (*V-Shape*). The appearance of the main window (MODEL B) with the input data is presented in Fig. 5, while the output optimization results of the model B are presented in Fig. 7.

4.2 Selection of the optimal solution

In the analysis of the input data for the variant solutions for the second variation for the pipeline route Beloševac - Divci, one can observe that the first variant is more favourable in all criteria in relation to the second variant, except for the utilities costs; however, this is exactly the criteria for achieving the greatest difference in the cost values and the greatest standard deviation.

In the model A, for the first three criteria related to the economic indicator, a regular preference function is selected and all three criteria are being equally treated, with the same weight coefficient. Out of these two variants, the optimal is the one whose criteria are more favourable. The graph (Tab. 9) of the regular function (*Usual*) indicates that it has a strict preference to select the optimal solution regardless the values in the difference of criteria. In this case, the difference in the criteria values does not influence the ranking order; hence, the variant with lower individual costs will be automatically selected. The action profile of the model A demonstrates that the variant 1 receives the maximum preference in relation to two economic factors, material costs and labour costs, while the variant 2 is dominant only with the utilities costs.

In accordance with the objective of the optimization, which is to minimize the pipeline construction costs, the significance of the ecological factor and the feasibility degree has been diminished. Both of these criteria have been designed as indicators rather than decision-making factors, in order to provide guidance if a small difference between the variants occurs.
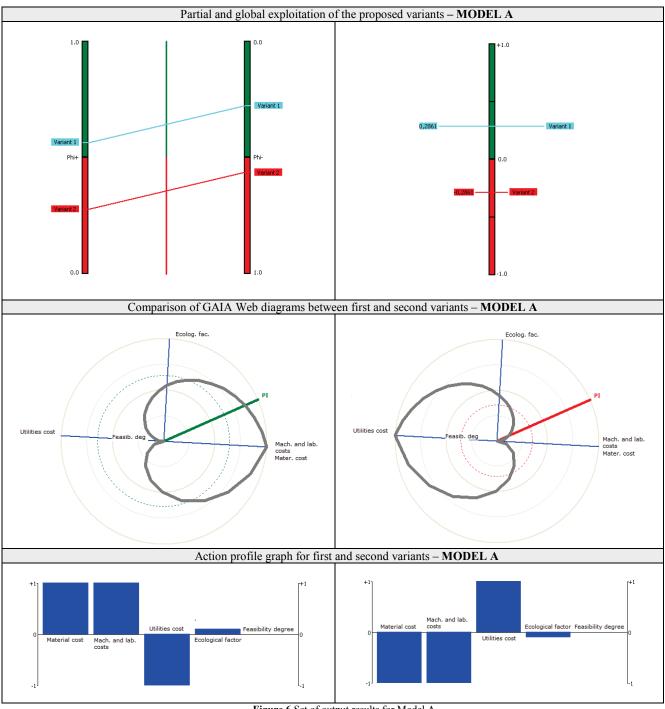
Partial and global exploitation of the proposed variants – **MODEL A**

Comparison of GAIA Web diagrams between first and second variants – **MODEL A**

Action profile graph for first and second variants – **MODEL A**

Figure 6 Set of output results for Model A

The results of partial and complete ranking of both variants, in Visual PROMETHEE software of the model A, presented in Fig. 5, demonstrate that the first variant is more favourable, with the grade value (preference) of the complete ranking (PROMETHEE II) being +0,2861; hence, it is proposed to the decision maker as the optimal variant for the pipeline route. When the overall costs (for first three criteria) are compared, the costs of the first variant (€331 129,81) are larger than the costs of the second variant (€317 001,19); therefore, the acceptance of the former (the first variant) would mean the acceptance of the more expensive solution, which is not in accordance with the set objective of the optimization (construction costs minimization).

In the second model, model B, for the first three criteria, instead of the usual preference function, the linear preference function is selected, so the variant receives the maximal preference only after reaching the value of the preference significance threshold (parameter p), which is determined by the decision maker. The difference in costs between the two variants is the greatest with utilities costs; therefore, in this model, the double value of the maximal standard deviation (utilities costs €27 400,70) is adopted for the value of the parameter p. In this manner, the evaluation considers the difference in the costs of the variants in question, which is equally important for the first three criteria. Then, the second variant of the pipeline route achieves the maximal preference (+1) for the utilities costs (Action profile graph – model B) (Fig. 7). The GAIA Web diagrams for the first and the second variant in the model B clearly demonstrate that the first variant almost has no contact with the decision axis PI,

making it absolutely inferior in relation to the other variant (Fig. 7).

In such modelling system, the second variant of the pipeline route receives the advantage in relation to the first one, by being evaluated in the complete ranking (PROMETHEE II) with the grade (preference) with the value +0,1349, providing a more realistic order of variants, since the overall costs in variant 2 are lower (Fig. 7). Based on the analysis of the output results of the software solution Visual PROMETHEE, the final decision is reached that in the second variation, the second variant for the pipeline route is more favourable than the first one, thus presenting the optimal solution. This variant is selected for construction.
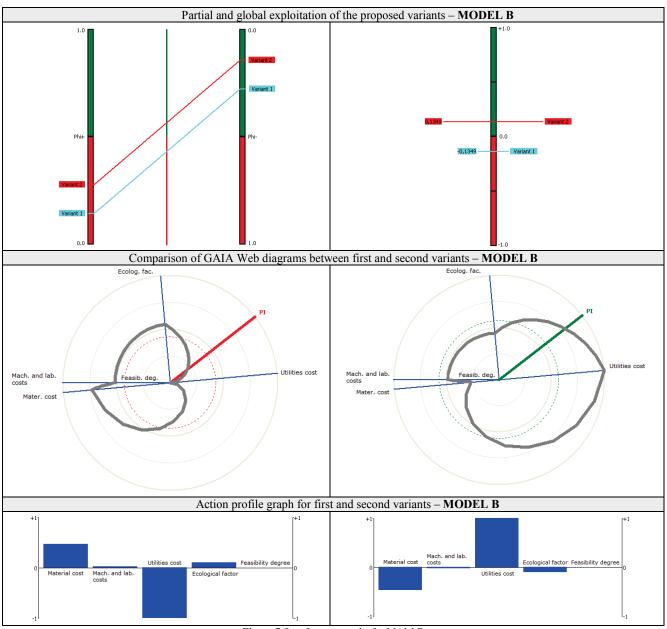

Figure 7 Set of output results for Model B

5 Optimal variants for the pipeline route Beloševac - Divci – results and discussion

The application of the method PROMETHEE and the implementation into the software solution Visual PROMETHEE evaluates five more variations on the route Beloševac - Divci, and the most favourable variants are selected.

Tab. 12 provides the input data (values of criteria for each variant individually), the selected preference functions and the output optimization results, as well as the most favourable variants for the pipeline route Beloševac - Divci (optimal solutions).

After the evaluation of six sections of the route for the regional pipeline Beloševac - Divci the following is determined:

FIRST VARIATION – The values of all three input data related to the costs are less in the second variant in this variation. First variant is advantageous only with the ecological factor. The adopted (usual) preference function sets advantage to the more favourable criteria (lower costs), regardless of the value of their differences, so the applied method PROMETHEE only confirmed that the second variant is the optimal solution.

SECOND VARIATION – The selection of the second variant in this variation is thoroughly explained in Section 4.

THIRD VARIATION - In this variation, first variant has the advantage in comparison to other two in material cost and labour cost, while the second variant has the advantage in utilities cost. The analysis of the output results using the PROMETHEE method demonstrates the advantage of the first route variant since the savings in the material price in the first variant are higher than the savings in the utilities cost in the second variant.

FOURTH VARIATION – In this variation, total costs (the sum of first three criteria), is almost identical for both variants, being (€446 065,39) in the first variant and (€446 079,21) in the second variant. The first variant is more favourable regarding material and labour costs, and

the second regarding utilities cost. The output results demonstrate the advantage of the second variant with the more favourable qualitative criteria (*EF* and *SI*) designed to overbalance towards closer results.

FIFTH VARIATION – After comparing the input data in all three proposed variants, a slight difference can be observed in labour cost and utilities cost. The decisive factor in the decision-making process in this case is the basic material costs. The output optimization results confirm the advantage of the second variant by gaining the highest preference.

SIXTH VARIATION – Input data in this variation provide advantage to the third variant in all criteria, which is confirmed by the Visual PROMETHEE software by gaining the highest preference.

Table 12 Optimal variants on the pipeline route Beloševac-Divci

Variation No. and variants	Input values					Output optimal variant
FIRST VARIATION	CM (€)	CR (€)	TR (€)	EF	SI	
Variant 1.	358 465,39	19 433,50	104 171,20	9	10	
Variant 2.	352 704,45	19 207,63	69 189,10	7	10	variant 2
	pref. functions					
	Usual	*Usual*	*Usual*	*V-Shape*	*V-Shape*	
SECOND VARIATION	CM (€)	CR (€)	TR (€)	EF	SI	
Variant 1.	227 479,82	14 075,59	89 574,40	10	9	
Variant 2.	240 231,31	14 596,58	62 173,30	5	9	variant 2
	pref. functions					
	Linear	*Linear*	*Linear*	*V-Shape*	*V-Shape*	
THIRD VARIATION	CM (€)	CR (€)	TR (€)	EF	SI	
Variant 1.	100 672,09	4 860,30	31 470,00	5	9	
Variant 2.	116 895,49	5 580,52	21 380,00	10	10	variant 1
Variant 3.	115 585,71	5 169,44	34 549,00	9	10	
	pref. functions					
	Linear	*Linear*	*Linear*	*V-Shape*	*V-Shape*	
FOURTH VARIATION	CM (€)	CR (€)	TR (€)	EF	SI	
Variant 1.	325 400,06	13 361,89	107 303,44	10	7	
Variant 2.	367 164,01	20 495,20	58 420,00	10	10	variant 2
	pref. functions					
	Linear	*Linear*	*Linear*	*V-Shape*	*V-Shape*	
FIFTH VARIATION	CM (€)	CR (€)	TR (€)	EF	SI	
Variant 1.	221 319,45	10 107,56	61 716,00	8	10	
Variant 2.	217 976,19	9 974,63	61 737,00	9	10	variant 2
Variant 3.	233 321,18	10 590,14	60 975,00	10	10	
	pref. functions					
	Linear	*Linear*	*Linear*	*V-Shape*	*V-Shape*	
SIXTH VARIATION	CM (€)	CR (€)	TR (€)	EF	SI	
Variant 1.	158 239,11	5 337,91	58 647,36	10	7	
Variant 2.	152 212,14	5 125,78	50 030,00	8	9	variant 3
Variant 3.	151 853,02	5 122,16	44 445,00	10	9	
	pref. functions					
	Linear	*Linear*	*Linear*	*V-Shape*	*V-Shape*	

Generally, it can be concluded that the pipeline type (materials, pipe diameter) and the location conditions influence the selection of the optimal solution for the pipeline route. The pipeline route Beloševac - Divci is designed as a steel pipeline with a large diameter, and the price of the material has a great impact in the overall costs. Hence, the pipeline route variants with less length gain advantage. In shorter routes, it is necessary to build smaller pipes, and in accordance with the set optimization objective, this manner is suitable for reducing the overall

construction costs. On the other hand, the works are conducted in a soft plain terrain. Hence, the excavation does not present a problem, nor are there any demands for special local reinforcement or concrete anchor blocks for pipeline support. In the observed variants for the pipeline routes, there are no extreme differences in the volume of excavation and the number of manholes (the construction of manholes can increase the construction costs due to the volume of reinforcement and steel), so the material costs are a primary factor. In the case when the pipeline has a

smaller cross section, with the other (cheaper) material for the pipes, it is possible to use the proposed analysis methodology and apply the PROMETHEE method by implementing it into the software solution Visual PROMETHEE in order to have the same procedure for proposing the decision maker the most favourable variant and for providing help in selecting the optimal solution. This presents a good basis for adopting the final solution for a concrete project, yet also opens the possibility for wider and more complex analyses for the influence of the pipeline type and location conditions onto the selection of the optimal pipeline variant.

6 Conclusion

The multi-criteria analysis for the route of the regional pipeline Beloševac - Divci, conducted on the basis of five criteria and applying the PROMETHEE method, has provided the optimal variants. The paper emphasises the significance of good modelling and the selection of the preference function that most realistically presents the analysed problem. The result of the application of the PROMETHEE method is partial and presents the complete ranking of variants; hence, the decision maker can adopt the final, optimal solution.

The PROMETHEE method has demonstrated to be applicable in real problems of engineering practice, during the construction planning phase. Using the PROMETHEE method, with the software support (Visual PROMETHEE 1.4), the users obtain fast and qualitative information that present a good foundation for the final decision-making. It is necessary to obtain the following:
– Gather relevant data and calculate the values for all analysis criteria,
– Generate possible variant solutions,
– Evaluate the variants using the PROMETHEE method (application of Visual PROMETHEE)
– Analyse the proposed most favourable variants, and
– Select the final variant (optimal solution).

The key to a qualitative analysis lies in a good preparation, as well as in gathering data and relevant factors that can influence the values of criteria, so that after the implementation of criteria the results are to be preferences with more precision.

The proposed evaluation model is based on three quantitative criteria, material costs, labour costs, and utilities costs. Since the qualitative criteria are not included into the optimization as decision-making factors, but are rather designed to provide advantage with close values, the proposed methodology provides optimal solutions for achieving the minimal construction costs.

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