APPLICATION OF THE MULTI-CRITERIA ANALYSIS FOR THE RAILWAY ROUTE EVALUATION AND SELECTION

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Abstract

After a detailed analysis of each railroad route alternative, the problem of route evaluation in the process of planning and designing is reduced to making a decision concerning its optimal selection. In this article the authors emphasize the significance of the reconstruction of the railroad route connection for the development of the North Adriatic Ports, Rijeka, Koper and Trieste. The most important project related to North Adriatic Port's railway transport system is the construction of a new high-efficiency railroad which will connect the ports of Rijeka, Koper and Trieste. The construction of a new high-efficiency railway will create a significant shortening of railroad links of South East Europe with its central and western parts and will improve the conditions of traffic exploitation of the North Adriatic transport route. The objective of this paper is to show that the application of the multi-criteria analysis can lead to conclusions regarding the evaluation and selection of the appropriate railroad transport route. In order to fulfill the research objective, a model comprising criteria and sub-criteria for railroad route evaluation is defined. The proposed model was used for the evaluation of the railway route Rijeka-Koper-Trieste by applying the PROMETHEE II method for multi-criteria ranking of alternatives.

Key words: railway transport system, North Adriatic Ports, multi-criteria analysis, railway route evaluation.

1. INTRODUCTION

North Adriatic Ports developed primarily due to their favourable geographical position at the intersection of the traffic direction Adriatic-Danube region. The North Adriatic Ports Association (NAPA) - comprising ports of Ravenna, Venice, Trieste, Koper, Rijeka, Monfalcone and Chioggia – has the main objective to direct the ports to operate in the international market as a single multi-port system. Ports agreed upon strengthening the links between transport infrastructure of the North Adriatic transport route and the Pan-European transport corridors, supporting inclusion of the Central European Transport Corridor in the TEN - T network (Perkovič et al., 2013, NAPA, 2020). NAPA ports act as mutually competitive port systems considering their common hinterland area. Beyond, they are representing common market competition toward other geo-traffic flows where goods from countries of Middle Europe are transported.

The general perspectives of this paper are the analysis of applying the model of the optimization of the selection of a railroad route by using the process of the multi-criteria ranking of variants. The set model was tested on an example of the analysis of the variants of the routes of the Rijeka – Koper – Trieste high efficiency railroad line connecting the three main North Adriatic Ports.

In the article Vilke et al. (2017) a model for the selection and evaluation of the optimal container transport route has been set and developed. The importance of certain groups of criteria and criteria respectively, determined in the model together with parameters' values of appropriate criteria for the defined variant solutions, were used as input data. Four possible transportation services, of which two variants comprising the Northern traffic flow and two comprising the Southern traffic flow through the NAPA ports respectively, were determined and analysed through the proposed model. Findings regarding optimal transport route determination were verified with the MCA application, applying the *Preference Ranking Organisation METHod for Enrichment of Evaluations* (PROMETHEE) and *Geometrical Analysis for Interactive Aid* (GAIA) methods using the *Visual PROMETHEE* software (Mareschal, 2013).

Kosijer et al. (2012) have developed a methodology for the selection of the railroad route that is based on the methods of multi-criteria decision-making. The verification of the proposed methodology was conducted on the example of the selection of one of the four variants of the railroad route on the section of Corridor X, between the Inđija and Novi Sad stations. In this research the method of multi-criteria compromise ranking VIKOR was applied enabling the choice of the railroad route through the evaluation of criteria expressed via quantitative as well as qualitative units. This method focuses on the ranking and selection of an alternative in the presence of conflict criteria, and the solution that is chosen is the one that is the closest to the optimal solution, which is a so-called compromise solution on the basis of the adopted measure of distance.

Krpan et al. (2017) have set the methodology for the selection of a railroad line in accordance with the process of the multi-criteria ranking of variants. In this research the adopted model consists of five sets of criteria each comprising u number of specific criteria. In accordance with the so-defined criteria and appropriate weighting coefficients, a multi-criteria analysis of the evaluation of the variants of the railroad line Rijeka – Koper – Trieste has been applied. The reliability and functionality of the proposed model has been proven through the conducted analysis.

The objective of the proposed paper representing the continuation of research (Krpan et al., 2017) is to justify the application of the multi-criteria analysis regarding the evaluation of the appropriate railroad transport route. Due to the impact of many parameters on the performance of an investment in the traffic infrastructure and a highly variable environment in which the project is implemented, this paper elaborates a new model for the evaluation of a railway line. The model for the evaluation of the railway line set in this paper contains a larger number of urban planning and a larger number of ecological criteria in relation to (Krpan et al., 2017) thus putting emphasis on the environment issue. Moreover, in this research there have been defined 11 extra criteria thus setting a wider analysis for the evaluation and selection of a railway transport route.

In order to perform the analysis following research questions have been set. Is the multi-criteria analysis, i.e. Promethee II, the appropriate method for evaluating and choosing the optimal railway route? What is the impact of economic criteria especially those concerning the costs of the route construction and maintenance? How does the constructional and urban-planning criteria affect on transport elements? What is the effect of the wide range of environmental features on the railway route eksploatation?

After determining the variants for the Rijeka – Koper – Trieste railway line, in accordance with the methodology of the process of the multi-criteria ranking of variants, the parameters of sub-criteria within the groups of the evaluation criteria have been defined. In accordance with the appropriate weighting coefficients, a multi-criteria analysis of the evaluation of variants has been applied using the PROMETHEE II method for multi-criteria ranking of alternatives.

2. GEO-TRAFFIC AND LOGISTICS ASPECTS OF NORTH ADRIATIC PORTS

North-Adriatic transport route with final points being ports of Rijeka Koper and Trieste, is the shortest natural thus the most economical way Europe is connected with the Mediterranean and, by sailing through the Suez Canal, with most of the countries in Asia, Africa and Australia. This route connects two economically complementary worlds: the industrially developed countries of Western Europe and the Asian and African developing countries (Kos et al., 2016).

The Northern Atlantic traffic direction with the ports of Hamburg, Rotterdam, Antwerp, Bremen and Amsterdam acts as dominant in the port service market. In spite of longer distance, utilization of the northern route is constantly increasing accentuating the competitiveness problem towards North Adriatic Ports. Greater distance is compensated with other logistic elements, such as contemporary roads and railway network, developed application of modern traffic technologies and cargo handling, operation organization on the overall transportation path, logistic and IT network, active ports' and railways' commercial and pricing policy, etc.

Table 1. Sea distances (in nautical miles) between ports of Rijeka (Croatia), Trieste (Italy) and Hamburg (Germany), and significant global ports

Port	Rijeka	Trieste	Hamburg
Port Said	1 254	1 294	3 551
Bombay	4 315	4 340	6 620
Shanghai	8 555	8 589	10 855
New York	4 785	4 814	3 535
Lagos	4 765	4 999	3 720
Buenos Aires	6 955	6 983	6 665
Singapore	6 275	6 308	8 585
Hong Kong	7 734	7 768	10 029

Sea distances from the Northern Adriatic ports to the Suez Channel represents one third of the same distance towards North Sea European ports. Considering Northern and Western European ports, sea distance from Far East ports and Northern Adriatic ports is approximately 2 000 nautical miles shorter, resulting in shorter travel/voyage time up to ten days (Table 1).

Considering land cargo traffic directions, main Central European industrial and commercial centres are closer to the North Adriatic ports for 400-600 km (Table 2). In spite of elaborated facts, present cargo flow in North Adriatic region is not suitable to its favourable geographical advantages, as the majority of traffic is passing through Northern and Western European ports. In general, goods originating from Danube region are faster and/or with lower process transported by longer but more contemporary inland transportation service, both roads and railways, and slower and/or with higher prices by using mountainous transportation links towards geographically closer/nearer Northern Adriatic ports. Prevalent factor for selecting the traffic flow, besides cargo transportation price, is the transport speed. Thus, two physically different distances are becoming economically equal, even pointing an economic advantage of the longer transportation route (Vilke, 2012).

Table 2. Railway distance (in km) of the Northern Adriatic and North European ports to specific Central European economic centres

Railway	Rijeka	Koper	Trieste	Hamburg	Rostock
Budapest	592	634	626	1406	1166
Bratislava	602	650	639	1022	980
Prague	806	854	810	686	644
Vienna	580	599	584	990	984
Linz	557	549	517	911	923
Munich	563	599	527	777	876

Important transportation links from landlocked Central European countries to seaports on the Adriatic coast intersect on the territory of Croatia, Slovenia and Italy with other important traffic flows which move from Central and Western Europe to

South-eastern Europe and the Middle East. Therefore, countries in the Northern Adriatic region act primarily as transit ones. Transport connection of the Danube and the Adriatic geographical area represents the connection of national areas with the Mediterranean area and its hinterland, which connects the continental countries of Central Europe with Mediterranean.

Movement of cargo flows and generation of particular traffic flows are nowadays governed by global logistics and large shipping companies according to their interests. In global and European market, the role of port systems considerably changed; certain advantages and drawbacks are evaluated by traffic and economic as well as political interests of individual countries. For instance, maritime cargo transportation from Asia to Malta employing the ship of equal size and general features is more expensive than from the same origin to the port of Hamburg, nevertheless the distance of the voyage. In general, the price of the total transportation from Asia to Hungary is approximately on the same level if it is conducted through northern Adriatic or North Western European ports. Thus, competitiveness of North Adriatic ports is reduced, while the selection of these ports depends primarily on large Asian carriers, as well as of countries governments' politics (Vilke et al., 2017).

3. MULTI-CRITERIA ANALYSIS – METHODOLOGY AND APPLICATION

A comprehensive valorization of individual variants of the route of inland traffic infrastructure is a complex and sensitive process that imposes an approach that takes into account the simultaneous effect of a number of different criteria. The concept that involves the ranking of individual variants and the selection of an optimal one in relation to the simultaneous effect of a number of different criteria is provided by the method of a multiple-criteria ranking of variants (Vilke et al., 2013).

Each multi-criteria problem consists of many different and in most cases contradictory criteria that may be of different significance for the decision-maker. Most methods for the selection of the best solution, i.e. methods for the multi-criteria decision-making require information about the relative importance of each criteria. The significance estimation of the criteria is assigned by the decision-maker himself or it is based on the opinion of the group of experts in the corresponding filed (Roubens, 1982).

General features of each multi-criteria problem, different from single criterion problems, consist of the following elements (Nikolić & Borović, 1996):

- more decision-making criteria (objective function, criteria function),
- more alternatives (solutions) to select from,
- the process of the selection of one alternative.

3.1. Application of the multi-criteria analysis in traffic planning and design

The prerequisite for the implementation of the multi-criteria analysis in transport planning and designing is the determination of the criteria and its importance and function, whose modification can lead to the perception of their impact to the selection of the optimal transport route. Since preferences being a relatively subjective factor, the intentions of a decision-maker are taken into consideration by defining the importance of the criteria in respect to their weighting coefficients.

One of the important prerequisites for reaching the desired effects of management and decision-making is making quality problem solving decisions in every phase. A decision maker is usually a natural or legal person who is responsible for the adoption of a final optimal solution or variant. That means, traffic experts are not the only ones who participate in the evaluation and selection of an optimal variant in traffic planning while an important role is played by officials at various levels of decision-making. Their primary role is to determine the criteria and preference structure and, with the help of experts, select a final solution. The structure of the decision-makers' preference is generally based on technical, economic, social and political criteria. If the preference structure is known before the optimization process, the decision-making process is relatively simple, and in the case of changes in the structure during the process, the process becomes much more complex (Karleuša et al., 2003).

The application of the multi-criteria analysis is acceptable under the following conditions:

1. a detailed definition of the criteria and an objective evaluation of their importance,
2. a detailed elaboration of variant solutions, i.e. an equal level of the processing of criteria for each variant, on the basis of which a mutual comparison of variants in relation to the accomplishment of criteria is possible,
3. an evaluation of all variants according to the adopted criteria,
4. a collaboration between the officials of the community and experts form different fields.

When analyzing the application of certain criteria in the procedures of transport planning and designing, it is clear that there are no dominant criteria, and that their importance varies depending on each individual problem. Individual problems of the selection of a potential transport route require the collection and analysis of a wide variety of data and include the work of experts from various fields. It is particularly important to include the public in the selection of potential solutions. The multi-criteria analysis as the process of evaluating and selecting the best scenario implies that the variant that gives the optimum value of the objective function according to the predetermined criteria is selected as the optimal variant. The problem of selecting the optimal variant in transport planning and designing is very compounded since all the conditions and limitations, which include technical, technological, physical, geographical, economic, ecological and other requirements, should be thoroughly taken into account.

3.2. The theoretical determinants of the PROMETHEE method

The objective of variant ranking is the reduction of the decision-making area and the quantified representation of facts that are important during the decision-making proceeding. The multi-criteria optimization is particularly important in the decision-making process of the selection of an optimal variant from a set of variants that differ depending on the acquired criteria. One of the most important methods of multi-criteria optimization is the PROMETHEE method. The method was defined and elaborated in the research conducted by Brans et al. in the year 1984.

The main settings on which the PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) method for a multi-criteria ranking of variants is based on are the following (Brans et al., 1984):

1. The coverage of the criteria.
2. The evaluation of the relation of a "higher rank".
3. The use of the relation of a higher rank.

The coverage of the criteria is based on the expansion of the criteria by introducing the preference function, which gives the preference of the decision-maker for the variant *a* in relation to the variant *b*. Thus, the preferences are modified in such a way that each criteria is observed through six possible functions of preference (six different types of criteria) based on their intensity. Some of them allow intransitivity of indifference, while others provide smooth or impulsive transfer from indifference to strict preference. The defined functions of preference or types of criteria can be used when solving the majority of the problems of multi-attribute decision-making.

The application of criteria set in this way allows the evaluation of a "higher rank". The relation of a higher rank is less sensitive to minor changes of parameters and its interpretation is rather simple.

Using the relation of a higher rank implies a specific use of an estimated relation of a "higher rank", especially in the case of variants that have to be ranked from the best to the worst ones. In this way, the PROMETHEE I method allows a partial ranking of variants, namely, the ranking that enables different variants to be at the same rank, thus allowing the utilization of certain ranks. Full ranking, in which each individual variant is distinctly ranked in dependence to the function of preference, may be achieved by means of the PROMETHEE II method (Brans et al., 1984).

The PROMETHEE II method for the multi-criteria ranking of alternatives is mostly used in practical application in transport planning and designing since it allows ranking determination. On the basis of the exact data input, this method enables both a partial and complete ranking of a large number of variants with respect to a larger number of criteria. The method provides the complete relation in which all the alternatives are completely ranked. The existence of a higher abstraction degree is enabled since part of information is lost due to the balanced effects between the input and output flow.

4. MODEL FOR THE EVALUATION OF A RAILROAD ROUTE

Given that the quality of the implemented selection procedure for the best railroad line variant and the accuracy of the final decision directly depend on the quality of the selected criteria, it is extremely important to do well in determining the criteria and measures for the optimization implementation. Experts must participate in defining the criteria to ensure that the assessment of the criteria importance does not succumb to a subjective approach (Vilke, 2013).

The most significant way for dividing the criteria for the evaluation and selection of the railroad traffic route is the one that makes a difference between the variants of the evaluation of the criteria. According to that, there are two different sets of criteria:

- a set of criteria that is evaluated on the basis of concrete, exact and quantitatively expressed data,
- a set of criteria that is evaluated on the basis of the subjective opinion of researchers who are assumed and required to have sufficient knowledge of the problems and criteria that they will be evaluating.

To set up a model for the evaluation and selection of the railroad transport route, the criteria and sub-criteria have been defined and their evaluation, i.e. the assigning of weighting coefficients has been performed. For the purpose of the evaluation and selection of the railroad routes and the application of the multi-criteria optimization method, criteria and sub-criteria were defined according to the information obtained from a large number of experts, planners, designers as well as scientific researches in the field of traffic planning. The criteria for the evaluation of railroad routes are divided into five thematic groups that are divided into less complex components or sub-criteria.

Table 3. Thematic groups of criteria and sub-criteria for evaluation and selection of a railroad route and their assigned weighting coefficients

CRITERIA (%)		SUB - CRITERIA	
		Full name	Value
Economic	**17%**	Costs of the of the route construction	26
		Costs of maintenance	15
		Costs of management	10
		Influence on the land depreciation of the local population	17
		Exploitation costs of rolling stock	8
		Development of tourism in the zone of influence	8
		Development of economic activities in the region	16
Transport	**25%**	Integration into the city railway system	6
		Integration into the intermodal traffic system	10
		Proximity of passenger aprons with regards to other traffic terminals	6
		Route position at the facilities	12
		Route length	8
		Capacity of railway line	17
		Train journey duration	12
		Transport reliability and speed	10
		Transport safety	19
Construction-techn	**10%**	Technical complexity of the construction of the route	38
		Terrain geology and seismology	20

CRITERIA (%)		**SUB - CRITERIA**	
		Full name	Value
		Passing of the route through common infrastructure corridors (yes/no)	18
		Availability of space (free land)	24
Urban planning	**23%**	Visual landscape impact	23
		Damage to the relief and possibilities of recovery	12
		Attracting other activities that endanger the geomorphological features of the area	11
		Impact on the development of the potential in urban planning	14
		Deviation of the route from the aviation line	5
		Space limitations	10
		Spatial units preservation and land taking	12
		The layout occupancy of the land area of particular variant solutions	13
Ecological-sociological	**25%**	Environmental impact	15
		Spatial impact	8
		Noise impact	7
		Vibrations impact	5
		Influence of meteorological conditions	4
		Impact of the route on the water and soil pollution	8
		Conservation restrictions	6
		Impact on the wider community	6
		Protected parts of nature and cultural heritage*	9
		Protected areas and habitat (ecological network)	11
		Influence on the population	9
		Distance from the tourist zones	6
		Distance from populated areas	6

Source: Prepared by authors according to (IGH, 2014.).

The model for the evaluation of the railroad route that includes the thematic groups of criteria and sub-criteria and their assigned weighting coefficients is presented in Table 3. The importance of the thematic groups of criteria is mutually compared and the weighting coefficients are normalized so that their sum is 100%. Furthermore, the weighting coefficients of the sub-criteria within a certain thematic group of criteria are normalized so that the total possible sum within each group of criteria amounts to 100%.

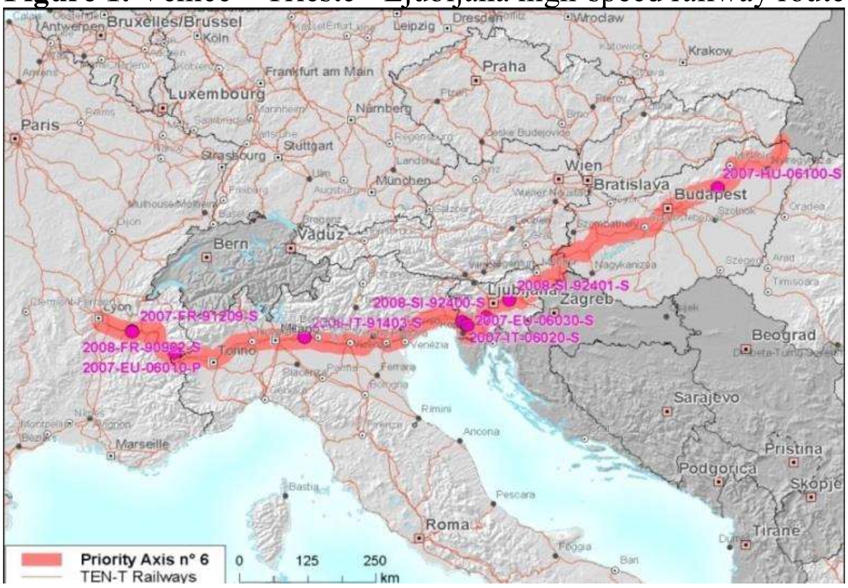
5. APPLICATION OF THE PROMETHEE METHOD IN THE PROCESS OF RAILROAD EVALUATION: RIJEKA-KOPER-TRIESTE RAILWAY LINE

For the optimization of the railway route selection that would connect the ports of Rijeka, Koper and Trieste, a process of the multi-criteria ranking of variants has been applied, the method PROMETHEE II, and the computer software for the multi-criteria optimization, "Visual PROMETHEE". For the evaluation of the railway route, the multi-criteria analysis was implemented in four phases in the following order:

1. determining of alternative solutions for the railway route,
2. evaluation of individual variants in accordance with the defined criteria and sub-criteria,
3. comparison and ranking of individual variants,
4. making of the decision on the optimal alternative solution.

Construction of high-speed railway from Northern Italy to Ljubljana has been included in Italian and Slovenian transportation policies' priorities as a part of Priority Project No.6 of the Trans-European transport network (TEN-T), or Pan-European Corridor V, respectively (Figure 1).

Figure 1. Venice – Trieste - Ljubljana high-speed railway route Venecija – Trst

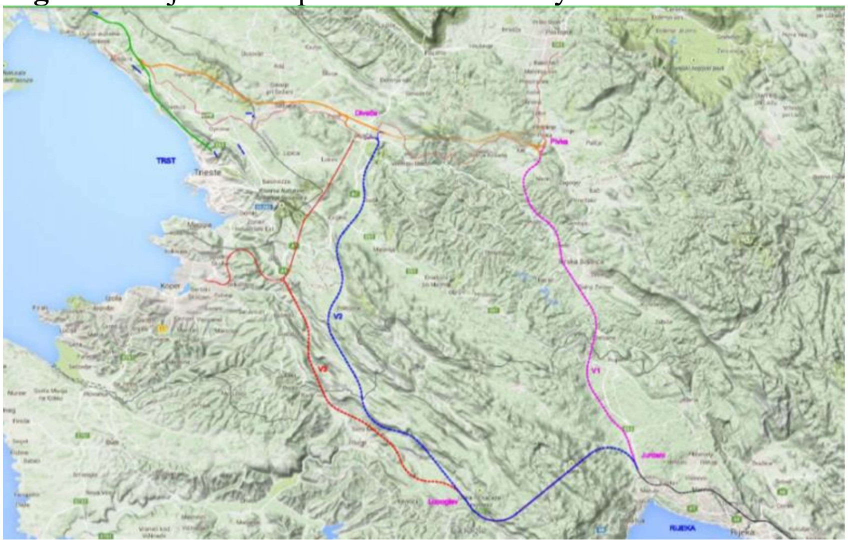


Source: EC, 2017

By analysing potential route corridors of the individual section Rijeka – Koper – Trieste, seven variants with several sub-variants have been selected (IGH, 2014.). After an analysis of significant environmental elements, investment costs and constructional-technical elements, three potential options have been selected. Variants of the railway route chosen for multi-criteria analysis are as follows: (Figure 2)

- Variant 1: Jurdani – Pivka train station – Divača train station,
- Variant 2: Jurdani – Divača train station,
- Variant 3: Jurdani – connection on new Koper – Divača railway line.

Figure 2. Rijeka – Koper – Trieste railway variants



Source: IGH, 2014

The research subject is the Rijeka (Jurdani) – Trieste (Opicina) railway section. There are existing plans for the railroad reconstruction starting from the Divača station, i.e. construction of new double-track from the Divača train station towards Trieste is planned. New tracks from Rijeka are planned in a way that the connection on planned railway is realized. Through the planned connection of Trieste - Aurissina - Palmanova - Venezia with previously described railway variant, interconnection of ports of Rijeka, Koper and Trieste is ensured. In this way, ports are connected on 6th TEN-T network corridor. As for port of Rijeka, it conjugates on a new railway Rijeka - Zagreb (EC 2017, Dundović *et al* 2010, Vilke *et al.* 2011).

5.1. An analysis of railroad route variants

All three selected variants for the railway connection of the North Adriatic ports begin at the Jurdani station near Rijeka. An overview of the defined railroad route variants is presented in Figure 3.

The Variant 1stretches from the Jurdani station through Ilirska Bistrica to the Pivka station. The length of the planned route is 35.9 km. Considering the connection of the railway from Pivka to Divača as the end point of all variants whose length will after the reconstruction amount to about 16 km, the total length of the route is approximately 51.70 km.

The coupling to the existing Divača – Pivka – Ljubljana railroad line is planned at the Pivka station. Through that railway line, a connection between Rijeka and Trieste and Koper is planned via the new Divača – Koper line. The route terminates at the Postojna station.

The total length of facilities of the proposed solution amounts to 19.3 km, of which 11.6 km comprises the length of bridges and viaducts and 7.7 km is the planned length of tunnels.

The railroad route of Variant 2 extends from the Jurdani train station over Lupoglava to the Divača train station. The total route length is 64.32 km, of which

35.4 km is situated on the territory of the Republic of Croatia and the remaining 28.92 km is located on the territory of the Republic of Slovenia.

The total length of facilities at the defined variant is 35.4 km, of which 6.5 km consists of bridges and viaducts and even 28.9 km is the proposed length of tunnels. That means, the share of bridges and viaducts on the route is more then 10 % and the share of tunnels is nearly 45 %.

As mentioned, the railroad route of Variant 3 extends from the Jurdani train station over Koper through the new railway line to Divača train station.

The total length of the planned railway line according to Variant 3 is 50.3 km, of which 38.5 km is situated on the territory of the Republic of Croatia and the remaining 11.8 km is located on the territory of the Republic of Slovenia. Accordingly, the share of bridges and viaducts on the defined route is more then 32 % and the share of tunnels is nearly 40 %.

Table 4. Criteria evaluation for railway variant solutions

CRITERIA (%)		SUB-CRITERIA Mark	Unit/ Object function	Variant I	Variant II	Variant III
Economic	17%	C1	Mil EUR Min	1366	1738	1976
		C2	000 EUR Min	1094	1943	1497
		C3	000 EUR Min	545	998	804
		C4	Rating Min	6	7	8
		C5	Rating Min	5	4	5
		C6	Yes/No Max	No	Yes	Yes
		C7	Yes/No Max	Yes	No	No
Transport	25%	C8	Yes/No Max	Yes	Yes	Yes
		C9	Yes/No Max	No	Yes	Yes
		C10	Rating Min	8	5	5
		C11	Rating Min	4	4	6
		C12	km Min	51.70	64.30	50.30
		C13	Rating Min	7	7	8
		C14	Rating	6	8	6

CRITERIA (%)		SUB-CRITERIA Mark	Unit/ Object function	Variant I	Variant II	Variant III
			Min			
		C15	Rating Min	5	5	7
		C16	Rating Min	6	6	7
Constructional-technical	**10%**	C17	Rating Min	2	3	5
		C18	Rating Min	0	0	0
		C19	Yes/No Max	No	Yes	Yes
		C20	Rating Min	2	4	6
Urban planning	**18%**	C21	Rating Min	2	8	6
		C22	Rating Min	2	6	4
		C23	Rating Min	0	0	0
		C24	Rating Min	2	5	7
		C25	Rating Min	5	4	4
		C26	Rating Min	5	7	4
		C27	Rating Min	5	7	4
		C28	Rating Min	5	8	5
Ecological-sociological	**25%**	C29	m min	17 214	30 467	26 466
		C30	Rating Min	2	7	5
		C31	Rating Min	4	5	3
		C32	Rating Min	6	4	4
		C33	Rating Min	3	8	2
		C34	m max	790	33 884	40 658

CRITERIA (%)		SUB-CRITERIA Mark	Unit/ Object function	Variant I	Variant II	Variant III
		C35	Rating Min	2	6	4
		C36	Rating Min	5	4	5
		C37	m max	13 478	21 558	32 746
		C38	m max	9 546	42 278	36 705
		C39	Rating Min	2	7	9
		C40	Rating Min	2	8	6
		C41	Rating Min	2	5	8

Source: Prepared by authors

The economic sub-criteria C1, C2 and C3 are expressed quantitatively in accordance with the estimated investment resources by experts according to (IGH, 2014.). For the sub-criteria C6, C7, C8, C9 and C19 the units of *yes/no* criteria are used, while for the transport sub-criteria the quantitative parameters, i.e. kilometers, were used. For ecological-sociological criteria C29, C34, C37 and C38, input parameters were obtained from GIS (Geographic Information System). Adequate parameters according to a rating scale from 0 to 10 were assigned to other sub-criteria. Furthermore, a corresponding object function, i.e. its minimum and maximum was assigned to each sub-criteria.

The evaluation of variants in respect to the projected investment costs was done on the data on their length, the number, size and type of facilities, as well as the bottom and top layout. Variants 2 and 3 have advantage over Variant 1 for connecting the Istrian railway lines in a unitary system of Croatian railroads. The most expensive solution for the construction of rail infrastructure is the third variant. The route of this variant, according to the project, includes the construction of a tunnel through Ćićarija with a total length of 15.9 kilometers. Moreover, on the section descending from Lupoglav to Buzet, it includes the construction of three viaducts with a total length of 11,1 kilometers. The junction that is particularly complex is the one to the planned Divača – Koper railroad line, where a connection with a large viaduct that should then connect to the Črni Kal viaduct on the Divača – Koper railroad line is planned. Concerning the sub-criteria of reliability and the speed of traffic and traffic safety closely related, variants were evaluated in accordance with the existing technical elements of the routes, i.e. data on the total length of the areas with the longitudinal inclination and their technical characteristics. Regarding the C27 and C28 sub-criteria, it should be said that the first two variants mostly pass through the agricultural and forest areas. Variant 3 is technically highly complex, especially in conducting the route from Lupoglava to the junction on to the planned Divača – Koper railroad line that was explained above. In the other hand, the variant three enables the possibility of including the route in the city railroad system and the possibility of integrating the route in the intermodal traffic system.

In relation to ecological-sociological criteria, it should be noted that the environmental impact, sub-criteria C29, is best ranked by Variant 1, the second is the Variant 3 and the third is the Variant 2. Since the density of housing at a distance of 100 m along the planned route is significantly present over the area of the norther route, Variant 3 was graded negatively according to C39. The analyzed routes of variants pass several times over a large number of watercourses and their tributaries. Moreover, in the passage areas of the variants there are protected areas of water sources. The ecological-sociological sub-criteria C37 and C38 (protected parts of nature and cultural heritage as well as protected areas and habitat) give advantage to the connection to the connection on new Koper – Divača railway line, i.e. Variant 3. Experts estimate that the northern solution has less influence on the groundwater pollution and soil pollution and degradation compared to Variants 1 and 2. The northern variant achieve a better synergy with the natural landscape, while the southern variants distort the appearance of the landscape thus degrading the space.

5.2. Discussion and results

For selecting the optimal railway route that will connect the ports of Rijeka, Koper and Trieste between the three defined variant solutions, the values of the sub-criteria determined in the previous chapter have been entered in the computer software for multi-criteria optimization "Visual PROMETHEE". Furthermore, the values of the importance criteria groups and the sub-criteria evaluated by researches and experts have also been entered in the computer program.

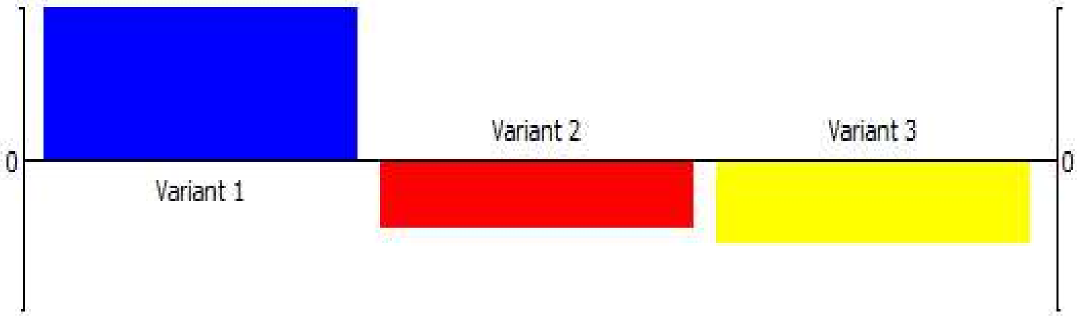
The multi-criteria optimization method PROMETHEE I gives calculated Phi values, i.e. input (-) and output (+) flows or the relations of the dominance of certain pairs of actions. The PROMETHEE II optimization method for multi-criteria analysis applied for this research gives the final obtained ranking of variant solutions based on the calculation of the net value of Phi. All the sub-criteria of evaluation are defined as Type 1 criteria for which it is not necessary to define additional parameters that specify the exact function of preferences.

Table 5. An overview of the result of the multi-criteria analysis of the selection of the Rijeka – Koper – Trieste railway line

Rank	*Railway route*	*Phi*	*Phi+*	*Phi-*
1.	Variant 1	0,4043	0,6140	0,2097
2.	Variant 2	-0,1860	0,3030	0,4890
3.	Variant 3	-0,2290	0,2910	0,5200

Source: Prepared by authors

Figure 5. An overview of the multi-criteria analysis of the selection of the Rijeka – Koper – Trieste railway line

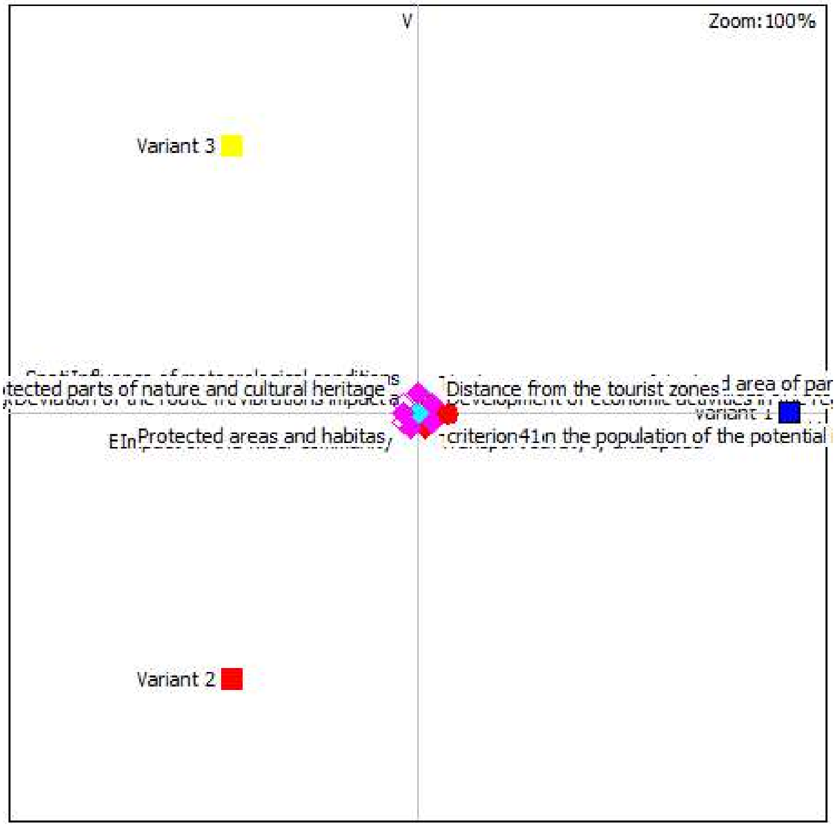


Source: Prepared by authors

Table 5 presents the obtained values for each individual variant and their positive and negative value of Phi thus presenting the results of numerical processing. A graphic overview of the numerical values of net flows is shown in Figure 5. The analyzed variants are ranked in the following order: Variant 1 with a value of net flow of is the optimal solution; Variant 2 is the second ranked selection with the expressed negative net flow of; the last place is occupied by Variant 3 with a clear negative net flow of. The route of Variant 1 dominates and is adequate for the selection of the railway line while Variants 2 and 3 are less suitable for the selection. However, the final choice will depend on the decision-maker and the objectives that have been defined.

Best results shown by Variant 1 derive from the better rated values of economic criteria in order it requires less investment resources. Moreover, Variant 1 is better assessed in terms of constructional-technical and urban-planning criteria deriving from the fact that Variants 2 and 3 are technically more complex. These two solutions include large tunnel lengths, more availability of space, leading the route at a higher altitude, large corrections of the existing railroad lines, arising to less rated values of the damage to the relief and possibilities of recovery and the formative influence to the new image of the area.

Figure 6. An overview of the results of the multi-criteria analysis in the GAIA plane



Source: Prepared by authors

A direct interpretation of the multi-criteria analysis in the GAIA (*"Geometrical Analysis for Interactive Aid"*) "u, v" plane which enables a visualization of the characteristics of optimization problem through geometric interpretation is shown in Figure 6. The grouping of variants signifies their similarities in terms of numerical values, while the dispersion means their diversity. The same applies for the sub-criteria: sub-criteria that are further away to each other have different numerical characteristics.

6. CONCLUSION

North-Adriatic transport route is the shortest, natural and the most economical way Europe is connected with the Mediterranean and, by sailing through the Suez Canal, with most of the countries in Asia, Africa and Australia. Within the narrow catchment area the ports of Rijeka, Koper and Trieste act as competitors. All three ports have the same natural gravitational fields, but there are certain differences in operating on the market.

In order to achieve complete connection between ports of Rijeka, Koper and Trieste the new railway line that will link the North Adriatic ports needs to be constructed. Interest in the completion of this railroad corridor, in addition to strengthening the position the entire system of North Adriatic ports, lies in the ability of routing freight traffic to Northern Adriatic.

The defining of groups of the criteria and sub-criteria for the evaluation and selection of the railway route and the appropriate weighting coefficients has been done on the basis on the information obtained from a large number of experts, scientific researches and planners in the field of rail transport planning. A model set in that way can be used in the process of rail route evaluation. Via a quantitative and qualitative evaluation of the criteria and sub-criteria, the efficiency and effectiveness of the model have been tested. By using the method of the multi-criteria analysis, more precisely the PROMETHEE II method, the evaluation and selection of the railway route linking Rijeka, Koper and Trieste has been conducted. Research results deriving form testing of the model prove the importance of applying the multi-criteria analysis in decision-making for railroad projects.

According to the conducted analysis the railway route of Variant 1, Jurdani – Pivka train station – Divača train station, was chosen as the optimal alternative. Since the other two variants have negative net flow results, they are less suitable for the selection. However, the final selection of the route of the Rijeka – Koper – Trieste railway line will depend on the decision-maker.

The research limitation of the research is the subjective evaluation of the criteria and sub-criteria for selecting the railroad route. As most of criteria are qualitative, the assigning of weighting coefficients has been performed according to the information obtained from experts and scientific researches in the field of traffic planning. For further, more detailed analysis, detailed dataset comprising additional criteria and results obtained by a wide questionnaire fulfilled by a larger number of experts, planners and designers in the field of transport and urban planning is required.

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