Evaluation of Alternative Solutions of General Design of Railway Lines with Regards to Environmental Protection

Ljubo Marković [1], Ljiljana Milić Marković[2], Srđan Jović[3], Miloš Milovančević[4]

[1] Faculty of Technical Sciences, University of Pristina, Kosovska Mitrovica, Serbia, ljubo.markovic@pr.ac.rs

[2] Faculty of Architecture, Civil Engineering and Geodesy, Univeristy of Banja Luka, Vojvode Stepe Stepanovića 77/3, Bosnia and Herzegovina, ljiljana.milic.markovic@aggf.unibl.org

[3] Faculty of Technical Sciences, University of Pristina, Kosovska Mitrovica, Serbia; srdjan.jovic@pr.ac.rs

[4] University of Niš, Faculty of Mechanical Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia, milovancevic@masfak.ni.ac.rs

Abstract: The railway, by its physical size, is a specific continuous object in an area whose impact on the environment can be extremely unfavorable. The changes occurring under the influence of these effects have a strong feedback effect that can lead to new negative states and often very dramatic consequences. In this paper, within the General project for the construction of infrastructure corridor in the central part of the Kolubara basin, the evaluation of alternative solutions for rail sections is shown for the protection of the environment through methodology of multi-criteria compromise ranking. Identified and quantified are adverse impacts on the environment in an area that is a potential corridor. To analyze the impact, taking into account their specific characteristics and spatial relationships, certain indicators for each of the alternative solutions are determined. The procedure and results of multi-criteria evaluation is also presented.

Keywords: General Design; railroad; environmental protection; multi-criteria evaluation

1 Introduction

With the development of technology man has greatly affected the environment not taking care of its preservation and protection from the negative impact of such development. The question of how to protect the nature from man that is "oneself from oneself" has become not only the theme of the day, but the concept without which it is impossible to reflect the modern world. Numerous experts in various studies are dealing with the identification of the key problems that we face in the environmental protection [1].

The European Union (EU) is also actively engaged in the issues of environmental protection. Currently, VI Action environmental program is in effect, which is implemented since 2002. The priorities of this program are: climate changes, nature and biodiversity, environment, health and quality of life, natural resources and waste.

Railway is one of the most efficient and environmental-friendly ways to transport people and goods. The results in article [2] have indicated that the environmental efficiency slowly increased during 2006-2011 and it exhibits regional disparities with the eastern area having the highest environmental efficiency and the western area being the lowest one and it was found a significant positive impact of railway transportation on higher environmental efficiency. Ballasted railway tracks, despite their benefits, present some limitations and drawbacks, mainly associated with geometry degradation due to ballast settlement and particle breakage [3]. The current closed, government-dominated decision making, opaque information provisioning, and lack of communication with and involvement of residents cause low levels of trust in railway-related local governmental agencies and companies [4]. There is increasing concern about environmental pollution by diffuse emissions of various environmental hazards emitted by transportation activities and selected studies may establish an understanding on relevant processes and environmental risk of railway emissions to soil, drainage water and groundwater [5]. Transport infrastructure is closely linked to several sustainability issues of main policy relevance, and significant impacts on biodiversity as well as resource use and construction costs relate to the corridor design and location in the landscape [6].

2 Environmental Protection Parameters in the Railway Lines Designing Process

The rapid economic growth and development directly affect the increased volume of all forms of transport. In the area of environmental protection, railway is the most acceptable form of transportation. Advantages of the use of railways in relation to other modes of transport (road and air) is reflected in the reduction of noise and air pollution, smaller impacts on flora and fauna, rail corridors occupy less arable land from a road, and the lower the cost of rehabilitation of the damaged environment [7]. European railway administrations, in accordance with the concept of sustainable transport EST (Environmentally Sustainable Transport) [8], are undertaking the following activities to protect the environment.

In the process of planning and design, the designers of railway examine all relationships between railway lines-environment. The success of design in the field of environmental protection from the negative impacts of the railroad requires a comprehensive review and definition of the effective parameters in relation to the main elements of the environment: climate, sound, soil, water, flora and fauna, landscape (Table 1).

Table 1
Matrix of relation railway and the environment [9]

	Settlements			**Rest Zones**		**Protection Zones**		**Water supply**		**Agriculture**				**Schemes**
	Urban type	Mixed	Rural type	Individual points	Rest zones surfaces	Natural reserves	Natural wholes	Water sources	Waters	Farmland	Orchards	Special cultures	Pastures and turfs	
Microclimate														
Air turbulation										*	*	*	*	*
Potential frost										*	*	*	*	
Appearance of fog										*	*	*	*	
Sound														
Noise	*	*	*	*	*									
Vibrations	*	*	*	*	*									
Soil														
Erosion										*	*	*		
Compaction													*	
Pollution										*	*	*	*	*
Water														
Surface waters pollution				*	*			*	*					
Underground waters pollution								*	*					
Changes in level						*	*			*	*	*	*	*
Fauna														
Species extinction					*	*	*							*
Extinction					*	*	*							*
Seizure of territory														
Flora														
Species extinction					*	*	*							
Obstruction					*	*	*							
Landscape														
Visual disturbances	*	*	*	*	*	*	*							
Changes of relief	*	*	*	*	*	*	*							
Intersecting the wholes	*	*	*	*	*	*	*	*	*					*

The process of creating design solutions for railway is designing real corridors - the routes the end result of which are various solutions on the corresponding substrates. In the railway design methodology four phases are defined: general design, conceptual design, operational project and archive project. In each of these phases also included is defining the environmental impact. Each project within a single methodology begins and ends with clear viewpoints as to provide optimal solutions.

2.1 Evaluation of Alternative Solutions in the Phase of General Project

The result of the general project is a defined corridor with offered alternatives – and the routes within it. In the process of valuation of the alternatives, for the choice of the optimal solution variation methods of multi-criteria evaluation (PROMETHEE, AHP, ELECTRE, VIKOR) are used. As a basis for the evaluation of alternative solutions an ordered list of objectives is formed: A – Construction costs; B – Costs of maintenance and management; C - Implications for users; D - Safety and comfort; E - Development and spatial effects; F – Environmental protection. Within each of these objectives the associated criteria and indicators are defined. Definition of goals, criteria and indicators is one of the most sensitive steps in the overall process of evaluating alternative solutions. The list defines the influences relevant to the offered route, quantifies their importance in specific conditions, i.e., it is about the procedures directly affecting the results of the evaluation of alternative solutions.

3 Environmental Protection (Objective F)

This objective includes minimizing adverse effects on the environment caused by the construction of the future route of the railway in terms of increased levels of noise, vibration, climate and microclimate, soil pollution, water pollution, soil occupation, degradation of flora and fauna. The omission of the aims from the evaluation process can have far-reaching consequences that culminate over time and lead to all serious forms of environmental degradation. Within the goal, defined criteria and indicators include the effects related to the consequences of the construction of the railway track to the environment. The basis for their definition are results supporting environmental studies and synthesis maps of limitation. The criteria are expressed in terms of partial utility score (P) of each criterion, i.e. evaluation of partial benefits for the individual criteria are added together with the use of relative weights. All the indicators of mentioned criteria are quantitative in nature. Table 2 provides an overview of the criteria and indicators that have been adopted on the basis of the analysis developed for the general design railways. Determination of relative weight of criteria and indicators is the obligation of the project team. Designers should critically consider, adopt or provide their proposals in accordance with the knowledge of specific areas and specific characteristics. Weight coefficients of the criteria and indicators cannot be determined on the basis of precisely defined data, but they are determined through expert judgment (survey procedure on specific groups of professionals) and/or by analysis of previous assessments, decisions and reactions of certain population groups through which the attitude of the community towards the above issues is quantified.

Table 2

Criteria and Indicators of F goal

CRITERION **K** / INDICATOR **P_f**		DIMENSIONS OF THE INDICATOR
K_{F1} NOISE		**min**
1.1.	Noise level during the day in settled areas	The area of number of people under the applicable levels
1.2.	Noise level during the night in settled areas	The area of number of people under the applicable levels
K_{F2} VIBRATIONS		**min**
2.1.	Vibrations level during the day in settled areas	The area of number of people under the applicable levels
2.2.	Vibrations level during the night in settled areas	The area of number of people under the applicable levels
2.3.	The facilities with sensitive equipment exposed to (day/night) vibrations	The area of number of people under the applicable levels
K_{F3} ELECTROMAGNETIC RADIATIONS		**min**
3.1.	Electromagnetic radiation in urban areas	The area of number of people under the applicable levels
K_{F4} WATER POLLUTION AND THE REGIME CHANGES		**min**
4.1.	Existing and planned areas for water supply	The surface of zone exposed to pollutants
4.2.	Surface water (liquid or stagnant) exposed to pollutants from traffic systems	Surface of areas endangered along the coast
4.3.	Changes in the underground regime	The area with the changes in the regime
4.4.	Changes in the surface water regime	The area with the changes in the regime
K_{F5} POLLUTION AND SOIL DEGRADATION		**min**
5.1.	Soil pollution (liquid solid pollutants) from the traffic system	The terrain surface being polluted or the pollutants quantity
5.2.	Soil degradation by erosion, landslide due to railway construction	Degraded soil surface
5.3.	Soil affected by the change of permeability	The area with the changes of permeability
K_{F6} FLORA AND FAUNA		**min**
6.1.	Presence of characteristic flora in areas along the tracks	The area with the characteristic flora
6.2.	Protected plant species endangered by the transport	The area underprotected plant species being endangered
6.3.	Protected animal species endangered by the transport	The area underprotected animal species being endangered
6.4.	Biodiversity	Number of certain plant and animal species being reduced
K_{F7} CLIMATE AND MICRO-CLIMATE		**min**
7.1.	Changes in climate characteristics	The area with altered climate characteristics
7.2.	Changes in micro-climate characteristics	The area with altered micro-climate characteristics
K_{F8} OCCUPYING AREAS		**min**
8.1.	Changes in the terrain morphology	The area with altered morphology
8.2.	Changes in terrain vegetation	The area with altered vegetation
8.3.	Changes in surface waters	The area with changes in surface waters
K_{F9} RAILWAY CONSTRUCTION RESOURCS		**min**
9.1.	Resources consumption for construction by type	The area with altered regime

Criterion K_{F1}: Noise

The sections are defined of the route passing through populated areas and the intensity of the noise equivalent level to medium (during the day and during the night) is determined and its impact in the area of *25 m* and *100 m* from the axis line. The noise impact, i.e. the level of noise endanger is expressed by the surface noise or by the number of people that are under applicable noise level during the day (an indicator $P_{F1.1}$) or night (indicator $P_{F1.2}$) in urban areas. Value of the criterion is obtained through the criteria function f_{F1}:

$$f_{F1} = \sum_{i=1}^{2} \omega_i P_{F1.i} \tag{1}$$

ω_i - weight coefficients for which applies, and $\sum_{i=1}^{2} \omega_i = 1$ (2)

Criterion K_{F2}: Vibrations

The sections are defined of the route passing through populated areas and the intensity of the vibrations through the level during the day ($P_{F2.1}$), and during the night ($P_{F2.2}$) is determined and its impact in the area of *100 m* from the axis track line. The effect of vibrations is expressed by the surface or the number of people under the applicable level of vibration during the day or night in the urban areas, or the number of buildings with sensitive equipment that is under applicable vibration levels during the day and night ($P_{F2.3}$). Values of the indicators are shown through partial benefit in the score of 1 to 10. Value of the criterion K_{F2} is obtained through the criteria function f_{F2}:

$$f_{F2} = \sum_{i=1}^{3} \omega_i P'_{F2.i} \tag{3}$$

where: $P'_{F2.i}$ - the values of the indicators reported through partial use

ω_i - weight coefficients for which applies, and $\sum_{i=1}^{3} \omega_i = 1$ (4)

Criterion K_{F3}: Electromagnetic Radiation

The sections of the route passing through populated areas are defined and the intensity of electromagnetic radiation and their influence in the corridor of the track is determined. This affect ($P_{F3.1}$) is shown by the area or group of people who are under the applicable level. The criteria value K_{F3} is obtained through the function f_{F3}:

$$f_{F3} = P_{F3.1.} = \sum_{j=1}^{n} q_{F3.1.j} \tag{5}$$

where $q_{F3.1.j}$ - the surface or number of people in the *j-th* section of the route is under the applicable electromagnetic radiation.

Criterion K_{F4}: Water Pollution and Changes in the Regime

The sections of the route are determined passing by the existing or future water supply zone, along the surface waters, the area where there is a change in the regime of water level and the level of contamination of water supply zones and coastal area due to contaminants of the transport system reaching the water is determined, that is the degree of change in the water level regime. These effects are shown through analytical indicators ($P_{F4.i}$):

$$P_{F4.i.}=\sum_{j=1}^{n} p_{F4.i.j} \tag{6}$$

Value of the criterion K_{F4} is obtained through the criteria function f_{F4}, by summarizing the above indicators $P_{F4.i}$ and the corresponding weight coefficients:

$$f_{F4} = \sum_{i=1}^{4} \omega_i P_{F4.i} \tag{7}$$

ω_i - weight coefficients for which applies, and $\sum_{i=1}^{4} \omega_i = 1$ (8)

Criterion K_{F5}: Pollution and Soil Degradation

The sections are determined where contamination can occur by a ground transportation system, degradation of soil by erosion and creeping due to railroad construction and changes in permeability. Value of the criterion K_{F5} is obtained through the criteria function f_{F5}, by summarizing the above indicators $P_{F5.i}$ and the corresponding weight coefficients:

$$P_{F5.i} = \sum_{j=1}^{n} p_{F5.i.j} \tag{9}$$

$$f_{F5} = \sum_{i=1}^{4} \omega_i P_{F5.i} \tag{10}$$

ω_i - weight coefficients for which applies and $\sum_{i=1}^{4} \omega_i = 1$ (11)

Criterion K_{F6}: Flora and Fauna

It is determined which sections of the route pass through an area of protected plant and animal species and the impact on the area is determined, as analytically indicated by the indicators:

$$P_{6.i} = \sum_{j=1}^{n} p_{F6.i.j} \tag{12}$$

where n is a number of protected plant and animal species.

Value of the criterion is obtained through the criteria function f_{F6} , by summarizing the above transformed indicators and the corresponding weight coefficients:

$$f_{F6} = \sum_{i=1}^{4} \omega_i P'_{F6.i} \tag{13}$$

where: $P_{F6.i}$ - the indicator is expressed through the partial benefit

ω_i - weight coefficients for which applies and $\sum_{i=1}^{4} \omega_i = 1$ (14)

Criterion K_{F7}: Climate and Micro-Climate

The sections of the route are determined where the consequences in the form of climate change, i.e. microclimate will occur. This is expressed analytically through indicators:

$$P_{F7.i} = \sum_{j=1}^{n} P_{F7.i.j} \tag{15}$$

where n is a number of consequences in the form of climate change.

The value of the criterion K_{F7} is obtained through the criteria function f_{F7}, by summarizing the above indicators $P_{F7.i}$ and the corresponding weight coefficients:

$$f_{F7} = \sum_{i=1}^{2} \omega_i P_{F7.i} \tag{16}$$

ω_i - weight coefficients for which applies and $\sum_{i=1}^{2} \omega_i = 1$ (17)

Criterion K_{F8}: Occupying Areas

The sections of the route are determined where there will be a change in morphology of the terrain, changes in vegetation composition and changes in surface water. These effects are shown analytically through the indicator:

$$P_{F8.i} = \sum_{j=1}^{n} p_{F8.i.j} \tag{18}$$

where n is a number of in morphology of the terrain, changes in vegetation composition and changes in surface water.

The value of the criterion K_{F8} is obtained through the criteria function f_{F8}, by summarizing the above indicator $P_{F8.i.}$ and the corresponding weight coefficients:

$$f_{F8} = \sum_{i=1}^{3} \omega_i P_{F8.i} \tag{19}$$

ω_i - weight coefficients for which applies and $\sum_{i=1}^{3} \omega_i = 1$ (20)

Criterion K_{F9}: Railway Construction Resources

Consumption of natural resources (gravel, sand, crushed stone, wood) to build the railway is expressed through K_{F9} criterion and the criterion function f_{F9} that is by the indicator $P_{F9.1}$. The value of the $P_{F9.1}$ indicator is obtained by summing the resources spent by type for certain positions of the construction works:

$$P_{F9.1} = \sum_{j=1}^{n} \omega_j a_j \tag{21}$$

where:

$P_{F9.1}$ - is the indicator defining the total amount of natural resources that will be spent for the construction of the railway

a_j - quantity of natural resources (*j-th* type) spent for the construction works of the railway;

ω_j - weight coefficients, which demonstrate the importance of a particular resource for the construction works.

K_{F9} criterion is obtained through the criterion function f_{F9} that is based on the indicator $P_{F9.1}$:

$$f_{F9} = P_{F9.1} \tag{22}$$

4 Example of Valuation Method Application

The industrial company Mining Basin "KOLUBARA" Ltd., in order to ensure safety in the operation of the entire power system of Serbia must open a new open pit mines as replacement capacity for existing mines due to increased production of TPP "Kolubara B". The main prerequisite for the construction of new mines is the relocation of significant infrastructure facilities: rivers, roads, railroads, industrial facilities, as well as settlements. In this regard, the formation of a new transport corridor is analyzed, which is defined in planning documents [10] [11]. Within the general project [12] for the relocation of infrastructure four alternative solutions for relocation of railroad sections of the railway Belgrade - Bar have been proposed. Also, proposed is the formation and development of studies on the impact on the environment of forming a corridor for the relocation of infrastructure [813].

4.1 Solutions of Relocation of the Railroad in the Central Part of the Kolubara Basin

Variant solutions (Figure 1) of the main railway Belgrade - Bar on the area in question were created in relation to a given corridor, the area for stable plants of mining complex, the position of relocated channel of the river Kolubara, technological bridge position and the mutual spatial relations of the river, railway and road. Boundary elements of the plan and profile are determined based on the given calculated speed Vr = 160 m/h. A cross-section of double track formation with a width of planum of 11.20 m has been adopted.

Variant Solution 1

In the first variant model solution the railway is relocated so that after leaving the existing corridor of the existing traffic the railroad crosses through the relocated channel of the river Kolubara in place of a technological bridge. In this solution railway crosses using an overpass of the technological bridge. Further the railroad is parallel to the displaced bed of the river Kolubara. Length of railroad dislocation per this version is 13.07 kilometers.

Variant Solution 2

In the second variant the railroad is relocated by the line running down the left side of the Kolubara River, passing under the technological bridge, continues parallel to the displaced river bed, crosses the South Peštan and fits into existing railroad. Length of railroad dislocation per this version is 12.01 kilometers.

Variant Solution 3

The third version of the track layout plan is fully consistent with option 2, but in this variant the track crosses the technology bridge with an overpass.

Variant Solution 4

In the fourth variant solution the railroad is displaced so that after leaving the existing traffic corridor the railway crosses the relocated Kolubara river bed in the third stage before the technological bridge, and then the technological bridge which after crossing the river has lowered down to the projected levels of the terrain. Further the railroad is parallel to the displaced bed of the river Kolubara (the left bank). Length of railroad dislocation per this version is 13.07 kilometers.

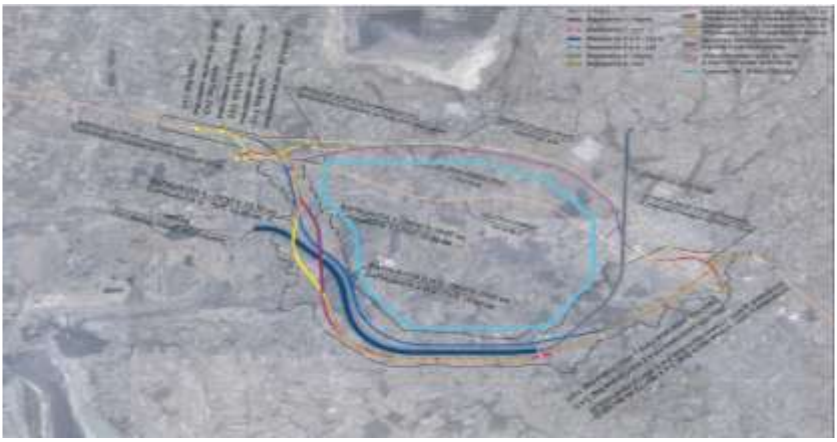

Figure 1
Overview map of the variant solutions [12]

4.2 Variant Solutions Valuation from the Aspect of Environmental Protection

The process of evaluating of variant solutions in terms of the impact on the environment aims at minimum adverse effects. Evaluation of the proposed variant solutions in terms of environmental protection has been performed using multi-criteria compromise ranking [14]. This method solves the optimization problem with multiple heterogeneous and conflicting criteria. The resulting solution is a compromise; it may be unique or represent sets of related solutions. The compromise solution is the one permissible solution that is closest to the ideal. The ideal solution is defined on the basis of best values criteria and is usually not in a given set of alternative solutions.

4.2.1 Variants, the Applicable Criteria and Relative Weights

The process of evaluating started by four alternative solutions of displacement of the Belgrade-Bar into the reserved corridor proposed at the level of General project [14]. Selection of the criteria and their partial participation (relative weight) were made based on experience in implementation of similar studies, project documentation and surveys where multidisciplinary team members took part.

To determine the relative weights of the criteria a simplified Delphi method on a sample of 30 respondents with average years of service over 30 was applied. Participants in the survey analyzed the importance of each criterion with respect to general knowledge and specific site conditions (Table 3).

Table 3
Criteria and criterion weight

Ord.no	Criterion	Criterion weight
1.	Noise	0.24
2.	Vibrations	0.13
3.	Water pollution and changes in the regime	0.16
4.	Pollution and soil degradation	0.17
5.	Flora and fauna	0.11
6.	Climate and micro-climate	0.06
7.	Occupying areas	0.13

For selected criteria the parameters and their quantitative representation have been defined. For each of the criteria the indicators are defined (Table 4) and their weights determined: P – Pronounced effect (ω_1=0,67); LP – Less pronounced effect (ω_2=0,33) and N – No effect (ω_3=0). All effects are reduced to a common unit (meter of track).

Table 4
Criteria, indicators and their quantitative views

Criterion (effect)	Indicator	Quantitative overview
Noise	Pronounced (P)	Length of the route through settlement
	Less pronounced (LP)	Settlements in the impact zone of 1,000 m
	No effect (N)	Remaining length of the route
Vibrations	Pronounced (P)	Length of the route through the archaeological sites
	Less pronounced (LP)	Length of the route through settlements
	No effect (N)	Remaining length of the route
Water pollution and changes in the regime	Pronounced (P)	The length of the route with watercourses closer than 100 m
	Less pronounced (LP)	Other watercourses in the area of 1000
	No effect (N)	Remaining length of the route
Pollution and soil degradation	Pronounced (P)	Length of the route through orchards, vineyards and fields
	Less pronounced (LP)	Length of the route through pastures, forests and other
	No effect (N)	Bridges, tunnels and settlements
Flora and fauna	Pronounced (P)	Length of the route through forests
	Less pronounced (LP)	All except forests and settlements
	No effect (N)	Length of the route through settlements

Criterion (effect)	Indicator	Quantitative overview
Climate and micro-climate	Pronounced (P)	The length of the embankment and the cut over 6 m
	Less pronounced (LP)	Other cuts and embankments
	No effect (N)	Tunnels and bridges
Occupying areas	Pronounced (P)	Route length through settlements, military and economic structures
	Less pronounced (LP)	Length of the route through the agricultural zones
	No effect (N)	Remaining length of the route

By reading the relevant data from thematic maps and by the quantification of the effects, the input data for the evaluation of variant solutions according to the adopted criteria were obtained (Table 5).

Table 5
Indicators for evaluating the effects

Variant solution	Degree of the pronounced effect	Noise	Vibrations	Water pollution	Pollution and soil degradation	Flora and fauna	Climate and micro-climate	Occupying areas
Variant 1	P	1060	7500	2455	57	250	3814	1060
	LP	3300	1060	1283	2343	1060	6275	2512
	N	8710	4509	9331	10669	11759	1283	9497
Variant 2	P	190	6560	2403	8	615	3026	190
	LP	2750	190	140	330	190	7163	2411
	N	9073	5263	9470	11675	11208	140	9412
Variant 3	P	190	6560	2403	8	615	1839	190
	LP	2750	190	1574	1764	190	6917	2411
	N	9073	5263	8036	10241	11208	1574	9412
Variant 4	P	1103	7425	2565	57	213	3376	1103
	LP	3245	1103	1210	2313	1103	6324	2621
	N	8758	4578	9331	10736	11790	1190	9382

4.2.2 The Results of Calculation and Analysis

Based on the performed procedures of evaluating variant solutions at the observed area using multi-criteria method of compromise ranking results were obtained by which the Variant 2 from the aspect of environmental protection has an advantage of 39.3% compared to Variant 3, 98.9% compared to Variant 4, while as compared to Variant 1 has an advantage of 99.3%. The obtained results of the valuation are presented in Table 6.

Table 6

Variant solutions ranking

Ord.no.	Advantage in %	Variant solution
1)	0	Variant 2
2)	39.3	Variant 3
3)	98,9	Variant 4
4)	99,3	Variant 1

Conclusions

Environmental protection is now a first-rate social problem. The protection of the environment in the process of designing railway is access in the earliest stages of making the technical documentation and it occupies the very top of the matrix of aims to evaluate the offered alternatives. This approach reduces the contingency fund for the execution of technical measures of precautions, i.e. reduces investment costs. In order to include the aspects of environmental protection into the methodology of evaluation of alternative solutions their comprehensive knowledge and determination is necessary. This paper presents a method of multi-criteria compromise ranking of alternative solutions and its application for the variant solutions evaluation as well as unambiguous definition of the optimal solution route for the protection of the environment during the preparation of the General Project of the railway. Based on the analysis of its effects it is concluded that the offered various solutions for the rail sections defined in the project will have a certain negative impact on the environment. Using these criteria of benefits of the area, from the standpoint of environmental protection, the optimal route of the railway in the studied corridor was adopted, which along with the necessary minimal measures of protection reduces the potential impact during the future railway exploitation to the smallest possible measure. As a result of application of the multi-criteria compromise ranking method the variant solution 2 was given priority as a compromise solution for making the final decision on the selection of optimal route.

For future unvestigation there is a need to increase protection modes and solutions [15, 16]. Also artificial intelligence techniques could be incorporated as well in the system.

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