APPLICATION OF DIFFERENT CRITERIA FOR CHOOSING AN OPTIMAL RAILWAY LINE

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Multicriteria analysis (MCA) has emerged as a valuable tool in railway decision making, enabling stakeholders to evaluate complex alternatives considering multiple conflicting criteria. Railway systems involve diverse and interrelated aspects, such as safety, efficiency, environmental impact, and cost – effectiveness.

This paper explores the application of MCA techniques in the context of railway decision making. First, it presents an overview of the key principles and methodologies of MCA, next, it explores the specific challenges and considerations when applying MCA in a real – world example of a railway decision-making, and lastly, the paper concludes with a discussion on the future prospects and emerging trends in MCA for decision making.

In summary, this paper emphases the significance of MCA in addressing the complexity of railway decision making by considering multiple criteria and stakeholder perspectives. It underscores the practical relevance of MCA methods, highlights challenges, provides examples, and explores future directions for the application of MCA in railway domain.

Keywords: designing, multicriteria analysis, Simple Additive Weighting (SAW), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), multicriteria optimization (VIKOR)

1. INTRODUCTION

The construction of infrastructure facilities begins with planning and design, an important process that anticipates needs and challenges that may arise during the construction and operation of the facility. Responsible planning and design helps to reduce investment costs and is a necessary part of the successful construction and operation of infrastructure facilities.

The design process focuses on solving problems in the urban environment by building new infrastructure, reconstructing the existing one or improving its management. Generating different variants, evaluating their advantages and limitations, and choosing the best solution are part of the process, the goal of which is to find an efficient solution to the problems in the environment.

Modern railways have many objectives to satisfy, including capacity, movement speed, transportation comfort, economic efficiency and protection of the environment. Some objectives require maximum values such as capacity, safety and transport quality, while others require minimum values such as construction investment, operating costs, travel time, construction time and environmental impact.

These goals are expressed in different ways – some quantitatively, others qualitatively, some in monetary values and others in time or evaluative parameters. This diversity of goals shows that the process of making a decision for the best solution is very complex.

In order to make the best solution, it is necessary to apply a complex and multi-step optimization process. First, a set of realistic variant solutions for the route is formed. Then, these solutions are evaluated according to the set criteria. The solutions are then ranked according to their value. Finally, they are analyzed and the most favorable solution for the route is selected.

Therefore, the purpose of multicriteria methods is to help in the decision making in choosing the best solution, or even to shorten the list of better solutions.

2. SUBJECT OF RESEARCH FOR THE APPLICATION OF MCA

The subject of research in this paper is the conceptual solutions for a railway line in Macedonia, between the city Strumica and the Border crossing to Bulgaria. Every solution will be analyzed by three different methods for MCA and a critical comparison of the obtained results will be made.

Methods of multicriteria analyzes that will be applied in the analyzes are the method SAW (Simple Additive Weighting), the method PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluations), and the method VIKOR (Multicriteria optimization).

2.1 SIMPLE ADDITIVE WEIGHTING METHOD (SAW)

The SAW method is a very commonly used method. The problem we analyze with this method is defined by setting different weight values for different criteria and evaluating them for each variant separately. The process of analyzing with the SAW method takes place in six steps:

Step I: Defining the criteria – in this step, the criteria according to which the variant solutions are evaluated will be defined.

Step II: Assigning weight coefficients – in this step, different weight coefficients are assigned for different criteria. This means that each criteria contributes differently in the final decision. In this case, the weight coefficients are determined with an anonymous survey of various experts in the considered areas.

Step III: Normalization of the values – in this step, we reduce the criteria to the same measurement unit as they would be comparable to each other.

Step IV: Evaluation of variants – in this step, we evaluate each variant according to each criteria.

Step V: Weighting sums – in this step, we multiply the normalized values of the criteria by the weight coefficients for each variant separately.

Step VI: Ranking – in this step, each of the variants is ranked according to the results obtained from the weighting of the sums.

The Simple Additive Weighting method offers a quick, direct and accurate way to rank multiple variant solutions. It is important to note that this method is very simple and that in itself gives some weakness. The weakness is that this method alone cannot determine whether the criteria being evaluated are dependent and related to each other. And if the user of the method does not establish it manually, the results with this method will lose their relevance.

2.2 PREFERENCE RANKING ORGANIZATION METHOD FOR ENRICHMENT EVALUATIONS (PROMETHEE)

PROMETHEE takes into account both positive and negative evaluation characteristics. It involves taking into account every advantage and every shortcoming of each of the variants that we analyze. In this variant of the method, the decision maker begins by identifying the relevant criteria for evaluating the variants. These criteria can be objective factors such as construction costs, construction duration, and subjective factors such as environmental impact and user satisfaction of the variant.

Once the criteria are determined, the decision maker defines preference functions to represent their preferences for each criterion. These preference functions can take different mathematical forms depending on the preferences of the decision maker and the nature of the criteria.

Next, the decision maker performs pairwise comparisons between each pair of alternatives on basis of each criterion. Comparisons are made using preference thresholds, which quantify the strength of preference. These preference thresholds are usually set by the decision maker.

By comparing the alternative pairs, the decision maker estimates the difference between them for each criterion. Positive flows indicate the superiority or benefit of the alternative over another, while negative flows indicate disadvantage.

After the currents are determined, the method calculates the advantages (in positive and negative sense) that measure the degree of dominance of one alternative over another. These calculated advantages take into account all criteria simultaneously and provide a comprehensive evaluation of the variants.

Then, based on the calculated advantages, this method generates a ranking of the variants. The ranking reflects the overall advantage or superiority of one alternative over another, taking into account positive and negative characteristics. The scorer can then interpret the ranking and make a decision based on the information provided.

2.3 MULTICRITERIA OPTIMIZATION (VIKOR)

VIKOR is a method for multicriteria optimization or multicriteria decision making. The method was developed by Serafim Opricovic for solving problems in decision making with conflicting and diverse criteria, assuming that the compromise is acceptable for resolving conflicts, that the decision maker wants a solution that is closest to the ideal and the alternatives are valued according to all the set criteria. VIKOR ranks the variants (alternatives) and determines the compromise solution that is closest to ideal.

This method focuses on variant ranking and selection in the presence of conflicting criteria, while using an ideal point as a reference point in the criterion function space. However, there is no variant that simultaneously satisfies all the criteria, so an admissible solution that is closest to the ideal in the space of criteria functions is sought. The solution that is closest to the ideal is called a compromise solution based on the adopted deviation measures.

3. DESCRIPTION OF VARIANTS

The route of a railway line in situation and longitudinal profile is subjected to strict design criteria of a safety and functional character. In order to connect Strumica with Bulgaria, through the “Novo Selo” border crossing, three variants have been created that are guided through fairly flat land with small height difference and they keep all the current standards for designing railways in Macedonia.

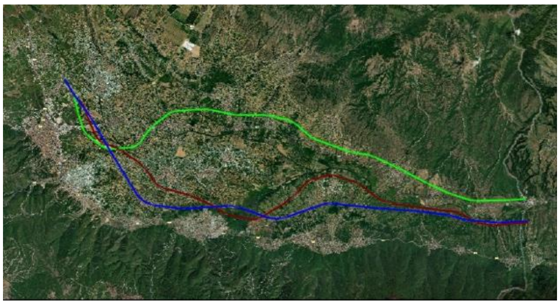

Figure 1. Situation of the three variant solutions Strumica – Border crossing

During the design of the three variants, all the design requirements are met including: maximum longitudinal slope 25‰, minimum radius of horizontal curve 300m, minimum radius of horizontal curve in station 500m, minimum intersection 150m, maximum longitudinal slope in station 1,5‰, interstation distance from 6 to 16km, minimum station plateau of 800m, maximum longitudinal slope in tunnel with lengths over 500m, 14‰.

It is important to note that when designing these three variants, the specified design conditions are oversized because the location conditions allow it, and they positively affect the comfort and long-term exploitation of the line. In fact, every designer aims to avoid the specified minimum parameters because the outcome is positive on a long-term level.

3.1 VARIANT 1 – RED

The starting point is the city of Strumica. Of course, a railway line to the city of Strumica has not yet been implemented, therefore, for all three variant solutions, a common initial railway station in the city of Strumica has been designed. The railway station is positioned 200 meters above the sea level. Specific to this variant is that the route follows the course of the Strumica river all the way to the border crossing itself. Starting from the thought that the flow of calm river naturally moves along the gentlest slope of the terrain, it is enough to follow the course of the river as a variant solution. The assumption is that the gentle slope of the terrain will have a positive effect on the longitudinal slopes of the route and most of the earthworks will be avoided. Of course, as can be concluded from the situation, the course of the river is not straight and with precise horizontal curves, so even during the design of the variant, the course of the river is taken as an orientation guide and it suffers major changes on the route. Along the route, two railway stations are planned apart from the starting and ending ones. The reason why only this variant has two stations unlike the others that have one station and one interchange is because this variant passes through several settlements. The variant solution ends with a train station in the immediate vicinity of the border crossing.

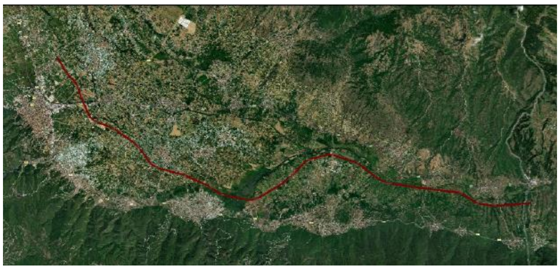

Figure 2. Variant route solution – Variant 1 – Red

3.2 VARIANT 2 – GREEN

The second variant solution is also specific in its own way. Unlike the first solution, where the direction of the route was the course of the river Strumica, in this case it is the main road A4 that leads to the border crossing “Novo Selo”. In terms of planning, the most efficient use of time is the application of already existing results. In this case, we know that the planners who designed the A4 highway did the same in order to take advantage of the most favorable conditions. If we follow that path, we know that most likely the route will go through the most favorable location. Starting from the common intended starting station in the city of Strumica, the route is in constant parallel movement with the main road, at a decent safety distance. The route, besides the starting station in the city of Strumica and the final station in the immediate vicinity of the border crossing “Novo Selo”, has one more station and one junction.

Table 1. Basic data for Variant 1 – Red

Route length	30,938.64m
Design speed	120km/h
Official slope	9.8‰
Minimum turning radius	800m
Number of stations	4
Number of interchanges	0
Number of culverts	61
Number of tunnels	0
Number of bridges	1
Bridge length	850.00m

Figure 3. Variant route solution – Variant 2 – Green

Table 2. Basic data for Variant 2 – Green

Route length	30,342.32m
Design speed	120km/h
Official slope	18.3‰
Minimum turning radius	800m
Number of stations	3
Number of interchanges	1
Number of culverts	55
Number of tunnels	3
Length of tunnel 1	337.21m
Length of tunnel 2	550.00m
Length of tunnel 2	800.00m
Number of bridges	1
Bridge length	150.00m

3.3 VARIANT 3 – BLUE

The third variant solution is formed to pass through the foot of the mountain Belasica. The purpose of this solution is to avoid the "Strumicko Pole" valley, and thus all possible intersections with roads, rivers and streams. This solution is different from the other two and the goal is to compare whether it is better to bypass the basin (and with it the costs for all overpasses and underpasses) and avoid potential pollution on nearby populated areas or is it more acceptable to avoid large slopes in the mountainous area and better economic picture of the route. This variant, like the other two, starts from the common starting railway station and the entire route moves through the boot of Belasica mountain. Apart from the starting and ending station, this route has one more railway station and one junction.

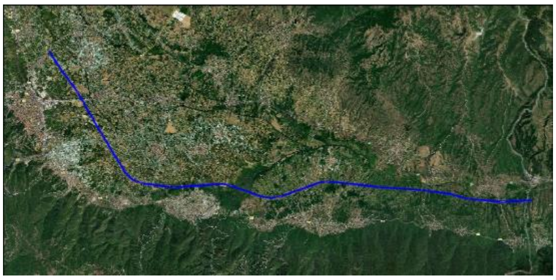

Figure 4. Variant route solution – Variant 3 – Blue

Table 3. Basic data for Variant 3 – Blue

Route length	30,222.48m
Design speed	120km/h
Official slope	17.2‰
Minimum turning radius	800m
Number of stations	3
Number of interchanges	1
Number of culverts	57
Number of tunnels	0
Number of bridges	2
Bridge 1 length	150.00m
Bridge 2 length	200.00m

4. APPLICATION OF MCA FOR CHOOSING THE MOST FAVORABLE OPTION

Before starting the analysis, it is necessary to determine the criteria by which the analysis will be performed. There is usually no limited number of criteria that can be applied to represent the characteristics of the studied phenomena. Applying a larger number of criteria does not necessarily mean that the analysis will be of higher quality. In order to choose a rational number of criteria, while not reducing the efficiency of the decision making process, it is necessary to apply the following principles when choosing criteria:

System principle – the selected criteria should represent the basic characteristics of the overall considered phenomenon;

Principle of consistency – one criterion should not include another criterion, i.e. the criteria should express the characteristics of the alternatives from a different point of view;

Principle of measurability – it is best if the criterion is measurable quantitatively, and if not, then it should be expressed qualitatively;

Principle of comparability – the decision maker will be able to make the decision more simply when the comparability of the criteria is obvious. In addition, the criteria must be normalized, so that they can be compared with each other because they are measured in different measurement units;

4.1 CRITERION 1 – ROUTE CONSTRUCTION INVESTMENTS

Investments for the construction of the route means all the financial investments of the investor for the performance of the construction works. This criterion is developed through pre-measurement and calculation. Estimates are made for all variants separately, the quantities for each position are taken, the cost prices of the positions are determined and the total cost of the route is formed. That actually represents an investment for the construction of the route. The final product of this criterion represents a quantitative value expressed in means of payment, usually millions of euros.

Table 4. Investment costs of all variant solutions

Variant 1 – Red	159,63 mil €
Variant 2 – Green	140,84 mil €
Variant 3 – Blue	86,10 mil €

4.2 CRITERION 2 – MANAGEMENT COSTS AND ROUTE MAINTENANCE AND TRAFFIC OPERATING COSTS

Companies that carry out transport should determine the prices of this type of transport service. The formation of costs and their analysis is usually done in two stages: first, the cost structure is defined, then each elemental cost is determined. The operating cost structure is usually grouped into the following segments:

Proportional costs that vary with kilometers traveled;

Fixed costs that are independent of the kilometers traveled in transport;

Direct costs that are related to newly offered services;

Table 5. Total costs for route management and maintenance

Variant 1 – Red	565.397,68 €
Variant 2 – Green	562.982,58 €
Variant 3 – Blue	562.497,23 €

4.3 CRITERION 3 – CONSTRUCTION – TECHNICAL CRITERION

Variant solutions of the route can also be evaluated based on construction – technical criteria such as lengths, heights to be overcome, slopes, number of stations and junctions, the percentage of the length of the route in objects, in curves, the size of the average radius etc.

For the technical comparison of the variant solutions for the route, in our case, one construction-technical criterion is used, because the road through which the route runs is quite flat, with a slight fall and a wide space for manipulation. In this case, if we were to apply criteria for overcoming heights, we would violate the integrity of the analysis because many unnecessary zeros would appear in the calculations. Therefore, in our case for this criterion we will use coefficient of the route in turns, because only that criterion is relevant.

Table 6. Coefficients from construction-technical criteria

Variant 1 – Red	0.3187
Variant 2 – Green	0.3062
Variant 3 – Blue	0.2278

4.4 CRITERION 4 – DURATION OF THE CONSTRUCTION WORKS

The criterion for the duration of the construction works is evaluated descriptively by ranking on a scale from 0 to 100, where a higher rating means a better ranking variant. The goal is to compare the construction works for the construction of the railway in the shortest possible period of time. The duration of construction works depends on several technical elements such as length of the railway track, number and total length of bridges and tunnels, amount of excavations and embankments, accessibility to the location.

Table 7. Ranking of variants according to criterion – duration of construction works

Variant 1 – Red	84.05 points
Variant 2 – Green	80.06 points
Variant 3 – Blue	85.27 points

4.5 CRITERION 5 – IMPACT OF THE ROUTE ON THE ENVIRONMENT

The basic information about the state of the environment and social conditions, in within the project environment, are based on data collected from direct communication with stakeholders, statistical data, project documentation, printed materials (strategic documents at national, regional and local level), visits to the project area, measurements of media quality and areas of environment (air quality, noise) etc. two types of data are most often used: directly collected data/measurements – refers to the sources of information collected directly in the project area, and indirectly collected data – refers to the data that has already been published/printed.

The use of this division in data collection serves to understand the concerns of local entities about environmental and social aspects, current social conditions and processes in the environment, cultural and social habits, as well as the socio-economic conditions of the residents in the project area, in terms of identifying potential impacts and how they can be avoided, minimized or mitigated.

In this paper, the criterion of the route's impact on the environment is considered by several key factors that contribute a different percentage to the final assessment, namely:

People factor (populated places and goods, noise and vibrations, emissions, recreational zones) which participates with 20% importance in the final assessment;

Flora and fauna factor (protected areas of international importance, protected areas of national importance, other important sensitive areas) which participates with 30% importance in the final assessment;

Soil and land use factor (agriculture, polluted areas, erosion) which participates with 5% importance in the final assessment;

Water factor (protected areas and use of water resources) which participates with 15% in the final assessment;

Air and climate factor which participates with 10% in the final assessment;

Landscape factor which participates with 5% in the final assessment;

Cultural and historical heritage factor which participates with 15% in the final assessment;

Table 8. Ranking of variants according to criterion – impact of the route on the environment

Variant 1 – Red	58.58 points
Variant 2 – Green	59.33 points
Variant 3 – Blue	55.67 points

4.6 DETERMINATION OF WEIGHTING COEFFICIENTS

After the selection of criteria that will be taken into account during the preparation of the MCA, a questionnaire is prepared regarding the weighting with weighting coefficients. The weighting of the coefficients was done using the Delphi method. This method is a systematic and interactive approach based of knowledge of independent experts. The method is based on the principle that the prediction of a group of experts is more accurate than the predictions of individual experts. The procedure consists in that, on two or more occasions, a group of well-chosen experts answers questions listed in a prepared questionnaire for selecting criteria. After each examination, the results of the selection of criteria with the reasons for their selection are submitted to all experts. In this way, it is suggested to the experts to create their previous selection of criteria taking into account the thoughts of the other experts from the group. This process stops when consensus or stable results are reached.

Table 9. Weighting coefficients table

C1	C2	C3	C4	C5
30%	26.15%	15%	16.54%	12.31%

4.7 MCA THROUGH SAW METHOD

In the very name of this method – Simple Additive Weighting, it is stated that this method is simple and we will not be wrong if we say that it is the simplest method for MCA. It is among the most frequently used methods and serves to make all kinds of decisions in everyday life, independent of construction.

Table 10. Ranking of variant solutions according to the SAW method

Variant	Points	Rank
Variant 1 – Red	0.811	3
Variant 2 – Green	0.831	2
Variant 3 – Blue	0.992	1

It can be seen from the table that the Variant 3 – Blue has the highest total and is ranked first, which means that when considering the given criteria and processing them with the obtained weight coefficients, it is recommended to choose the Variant 3 – blue in the process of further designing.

4.8 MCA THROUGH PROMETHEE II METHOD

The PROMETHEE method is much more serious method compared to SAW. This method exists for more than 40 years, and its reliability is evidenced by the constant improvement and creation of new versions of the method. The PROMETHEE method counts six versions covering different areas of learning and different approaches to valuations. In this paper, and as the most valid for our case, we will use the second method, PROMETHEE II, which represents a complete ranking of a given problem.

Table 11. Ranking of variant solutions according to the PROMETHEE II method

Variant	Sync index	Rank
Variant 1 – Red	-0.43	3
Variant 2 – Green	-0.11	2
Variant 3 – Blue	0.55	1

From the calculations made according to the PROMETHEE II method, the result was that the most favorable variant solution is the Variant 3 – Blue.

4.9 MCA THROUGH VIKOR METHOD

VIKOR is a method for multicriteria optimization or multicriteria decision making. The method was developed for solving problems when deciding with conflicting and diverse criteria, that the decision maker wants a solution that is closest to the ideal and that the alternatives are evaluated according to all the set criteria. VIKOR ranks the variants and determines a compromise solution that is closest to the ideal.

Table 12. Ranking of variant solutions according to the VIKOR method

Variant	Rank
Variant 1 – Red	3
Variant 2 – Green	2
Variant 3 – Blue	1

The results of the conducted multicriteria ranking using the VIKOR method show that the Variant 3 – Blue is the most favorable solution for all scenarios. Therefore Variant 3 – Blue is proposed as a compromise solution.

5. CONCLUSION

Analyzing the final results of all three multicriteria methods, it can be concluded that the Variant 3 – Blue is the best solution among the three offered solutions, according to all multicriteria analyses.

If a review is made of the practical application of the three methods for MCA, it can be concluded that they are a tool that is really of considerable help when the task is to make a decision to choose the most favorable variant solution in relation to several criteria. Regarding the applied methods, it is evident from the performed calculations that all methods give the same result, i.e. from the MCA carried out after all three considered methods, the result was obtained that the Variant 3 – Blue is the best variant compared to the other two depending on the different criteria which are taken into account.

Based on everything presented in this paper, it can be concluded that MCA, with proper definition and calibration, facilitate the process of designing and making a decision, a decision that benefits all parties concerned with the project.

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