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Ranking of Alternative Highway Route Solutions Using the AHP Method

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ABSTRACT

Designing road projects involves a complex decision-making process whose objectives should be the implementation of the road design and its utilization in the narrowest sense, but also the facilitation of mobility, economic development of the area and improvement of the quality of life in a wider sense. All of this requires the consideration and understanding of many problems of a multi-criterial nature, . The main goal of this paper is to use a real example to explain the role and significance of multi-criteria evaluation methods. The theoretical steps of multi-criteria evaluation are presented (the AHP method). Using multi-criteria evaluation method ranking was carried out of the alternative solutions offered for the E-763 highway route Belgrade - South Adriatic (Požega – Boljare section). Ranking was carried out on the basis of 12 criteria . The calculation was performed by using the software package Expert Choice 2000 and an analysis of the results obtained was carried out.

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1. Introduction

Transportation, as an organized activity involving the movement of people and goods, represents one of the fundamental prerequisites for dynamic economic growth in a country. It contributes to increased productivity, competitiveness, employment, and facilitates faster and higher-quality exchange of goods and services with the surrounding region and the world. Transportation is a key factor not only in societal development but also in the survival of a particular community. This activity represents the "social bloodstream," and areas where "transportation arteries" do not reach tend to experience demographic decline.

2. Evaluation of Road Project Solutions

Road design, from project identification through route selection to final project realization and evaluation, represents a lengthy and complex process. The result of the design process consists of proposed alternative solutions based on appropriate grounds. In order to select the most favorable option and make a decision to proceed to the next phase of design, the proposed alternative solutions are subject to an evaluation procedure.

The term evaluation implies a process of assessment that involves procedures for defining criteria (performance parameters of alternatives) and indicators (actual values for each criterion) relevant for assessing the proposed alternative solutions. In order for the evaluation to lead to optimal solutions, it should be based on:

- Economic evaluation: assesses the project's contribution to the country's economic welfare;
- Environmental impact assessment: involves evaluating the impact of the road facility (existing and newly constructed or rehabilitated) on the environment;
- Financial evaluation: conducted in the process of securing investment funds for the implementation of the optimal project solution.

3. Multi-Criteria Evaluation

Multi-criteria evaluation involves decision-making in cases where there are multiple and mutually conflicting criteria (Marković et al., 2013). Depending on the nature of each specific problem, three basic approaches to its solution are possible: ranking problem - ranking the set of all alternatives (projects) from "best" to "worst"; selecting one alternative - choosing the "best" alternative; selecting multiple alternatives - choosing multiple alternatives, where starting from the highest rank, a predefined number of alternatives is adopted (Lu et al., 2007).

4. Analytic Hierarchy Process (AHP) Method

The Analytic Hierarchy Process (AHP) is one of the most commonly used multi-criteria methods in cases where the choice of one of the available alternatives or their ranking is based on multiple attributes that have different importance and are expressed using different scales. The AHP method enables flexibility in the decision-making process and helps decision-makers prioritize and make quality decisions (Saaty & Kearns, 1991).

AHP allows for the interactive creation of a problem hierarchy as preparation for decision-making scenarios, followed by pairwise evaluation of hierarchy elements (goals, criteria, and alternatives) in a top-down direction (Saaty, 1980). In addition, during the evaluation of hierarchy elements, the consistency of decision-makers' reasoning is checked, and the correctness of the obtained rankings of alternatives and criteria, as well as their weighting values, is determined.

Four steps of this method are distinguished:

- Structuring the problem: The hierarchical structured decision model typically consists of goals, criteria, several levels of sub-criteria, and alternatives.
- Data collection and analysis: The decision-maker assigns relative scores for pairs of criteria at one hierarchical level for all levels of the entire hierarchy. The Saaty scale of evaluation is used for this purpose (Coyle, 2004).
- Calculation of relative criterion weights: The pairwise comparison matrix is translated into a problem of determining eigenvalues to obtain normalized and unique eigenvector weights for all criteria at each level of the hierarchy. Weight coefficients are calculated for each element at a given level (Saaty, 1990).
- Determining the problem solution: This involves finding the so-called composite normalized vector. After determining the sequence vector of criterion activities in the model, in the next round, it is necessary to establish the order of importance of alternatives in the model within each observed criterion.

The consistency ratio (CR) is calculated using the formula:

$$CR = \frac{CI}{RI} \tag{1}$$

Where: CI - consistency index

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

λ_max - maximal eigenvalue of the comparison matrix

$$\lambda_{\max} = \sum_{i=1} \lambda_i \quad (3)$$

RI - random index depending on the order of the comparison matrix.

If the consistency ratio (CR) is less than 0.10, the result is sufficiently accurate and there is no need for adjustments in comparisons and recalculations. In practice, it happens that the consistency ratio is higher than 0.10, yet the selected alternative remains the best.

5. Evaluation of Offered Solutions Using the AHP Method

5.1. Subject of Evaluation

Within the framework of the General project of the E-763 highway from Belgrade to the Southern Adriatic (Saobraćajni Institut CIP, 2007), on the section from Požega to the border with Montenegro (Boljare), four project solutions have been designed: West; Center; East 1 and East 2 (Figure 1). Through multi-criteria evaluation of the proposed project solutions, the most acceptable ones need to be selected to proceed with further development of the project documentation.

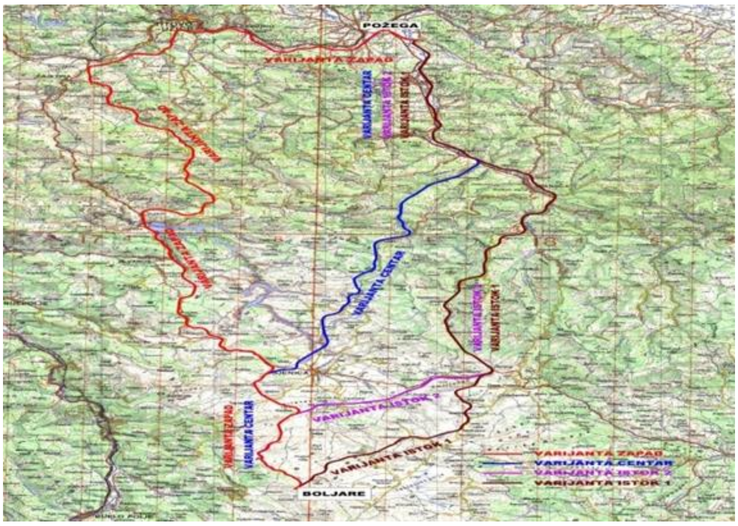

Figure 1. Proposed highway route solutions (Saobraćajni Institut CIP, 2007)

5.2. Project Objectives, Criteria, and Evaluation Indicators

Project Objectives:

- Improve the level of service for forecasted traffic flows on the road network within the corridor of the planned highway.
- Enhance traffic safety levels for forecasted traffic flows on the road network within the corridor of the planned highway.
- Reduce operational costs for users for forecasted traffic flows on the road network within the corridor of the planned highway.
- Enable optimal serviceability with a high-capacity and high-quality roadway for existing settlements, functional units, and road networks.
- Maximize environmental preservation within the corridor of the planned highway.
- Facilitate the faster development of the catchment area.

Multi-criteria evaluation of alternative project solutions involves consideration from various aspects: investment-construction, traffic-operational, spatial-urban, ecological, and socio-economic. Based on this, criteria were selected and elaborated through corresponding indicators. Table 1 shows the selected criteria and their respective indicators.

Table 1. Selected criteria and indicators

Criteria	ext.	Indicators
Investment construction costs	min	Preliminary and preparatory works; Lower structure Drainage and drainage; Upper structure Grade-separated intersections; Environmental protection facilities Relocation of roads and other installations; Traffic signaling
Operational costs User	min	Fuel costs; Lubricant costs; Tire costs Maintenance and repair costs; Additional costs Time-dependent costs (depreciation, interest, overhead, salaries)
Maintenance costs	min	Length (km) Regular, winter, and increased maintenance costs
Total accident costs	min	Number of accidents (number of fatalities, number of injuries, material damage) Accident consequences (number of fatalities, number of injuries, material damage)
Travel time	min	Length (km); Longitudinal slope (%); Speed (km/h)
Collision of highway variants with settlements	min	Arable land; Forests; Urbanized areas; Meadows and pastures; Orchards and vineyards.
Spatial conflict with existing land use	min	Ratio of the highway corridor AP to residential areas ; Ratio of the highway corridor AP to industrial zones; Ratio of the highway route AP to existing land use structure.
Degradation of future spatial planning possibilities	min	he corridor limits further development and cuts through settlements; the corridor passes at a distance of less than 500m and partially limits further development of settlements; the corridor passes at a distance of more than 500m and does not limit further development.
Functionality of connecting spatial units and activating development potentials	max	Functional connection of settlements: the corridor connects 6 or more settlements (municipal centers); the corridor connects up to 5 settlements (municipal centers); Possibility of activating tourism potentials: the corridor connects a larger number of zones and sites; the corridor connects a smaller number of zones and sites; the corridor does not connect any tourism zone or site.
Destruction of cultural and natural values	min	Cultural monuments and archaeological sites in the impact zone; Protected natural assets in the impact zone.
Relation to environmental consequences	min	Noise; Air pollution; Water pollution; Soil pollution; Flora and fauna; Vibrations; Other.
Impact on social development and indirect economic effects	max	Tourism development; Agriculture development; Changes in employment structure; Increase in land rental potential; Property value changes; Population retention; Increase in quality of life.

5.3. Selection of the Most Favorable Alternative Route Solution Using the AHP Method

The problem of selecting the most favorable alternative solution is decomposed into a second hierarchical level consisting of criteria and is directly related to alternative solutions. In this case, 12 criteria are grouped into four categories:

- Costs;
- Travel time;
- Spatial aspects;
- Environmental and sociological aspects.

Based on expert assessment, an appropriate comparison matrix (Table 2) was generated using the Saaty scale to express the relative importance among the four groups of criteria (Costs - tr, Travel time - tt, Spatial aspects - pr, Environmental and sociological aspects - eks):

Table 2. Comparison Matrix

$$\begin{bmatrix} 1 & tr/vr & tr/pr & tr/eks \\ vr/tr & 1 & vr/pr & vr/eks \\ pr/tr & pr/vr & 1 & pr/eks \\ eks/tr & eks/vr & eks/pr & 1 \end{bmatrix} = \begin{bmatrix} 1 & 2 & 4 & 5 \\ 0,50 & 1 & 3 & 6 \\ 0,25 & 0,33 & 1 & 2 \\ 0,25 & 0,17 & 0,50 & 1 \end{bmatrix}$$

The matrices of comparative analysis of offered variant solutions based on four groups of criteria are presented in tabular form (Tables 3-6):

Table 3. Cost Criterion

Cost (tr)	West	Center	East 1	East 2
West	1	1/7	1/6	1/5
Centar	7	1	6	5
East 1	6	1/6	1	1/2
East 2	5	1/5	2	1

The matrices of comparative analysis of offered variant solutions based on four groups of criteria are presented in tabular form (Tables 3-6):

Table 4. Travel Time Criterion

Travel Time (vr)	West	Center	East 1	East 2
West	1	1/7	1/5	1/6
Center	7	1	2	3
East 1	5	1/2	1	1/2
East 2	6	1/3	2	1

The matrices of comparative analysis of offered variant solutions based on four groups of criteria are presented in tabular form (Tables 3-6):

Table 5. Spatial Aspects Criterion

Spatial Aspects (pr)	West	Center	East 1	East 2
West	1	1/9	1/5	1/5
Center	9	1	5	2
East 1	5	1/5	1	2
East 2	5	1/2	1/2	1

The matrices of comparative analysis of offered variant solutions based on four groups of criteria are presented in tabular form (Tables 3-6):

Table 6. Environmental and Sociological Aspects Criterion

Environmental and Sociological Aspects (eks)	West	Center	East 1	East 2
West	1	1/7	1/7	1/4
Center	7	1	2	4
East 1	7	1/5	1	2
East 2	4	1/4	1/2	1

Determining the relative weights from the comparison matrices of alternative solutions based on criteria:

$$(tr) = \begin{bmatrix} 0,0433 \\ 0,623 \\ 0,138 \\ 0,195 \end{bmatrix} \quad (vr) = \begin{bmatrix} 0,05 \\ 0,482 \\ 0,20 \\ 0,26 \end{bmatrix}$$

$$(pr) = \begin{bmatrix} 0,0462 \\ 0,552 \\ 0,213 \\ 0,189 \end{bmatrix} \quad (eks) = \begin{bmatrix} 0,0488 \\ 0,50 \\ 0,297 \\ 0,154 \end{bmatrix}$$

5.3.1. Determination of the problem solution

Matrix of total weights for all four alternative solutions (West, Center, East 1, East 2):

$$\sum = \begin{bmatrix} 0,046244 \\ 0,5590 \\ 0,17859 \\ 0,21286 \end{bmatrix}$$

Results of consistency testing: $\lambda max=4.0747$ CI= 0.002491 CR=0.0277<0.10

Based on the given criteria and pairwise comparison ratings of alternative solutions and criteria, the ranking of variants using the AHP method yielded the following results (Table 7):

Table 7. Ranking Results

Rank	Alternative Solution	Weight of Alternative Solution
1	Center	0.5590
2	East 2	0.21286
3	East 1	0.17859
4	West	0.046244

6. Conclusion

This study analyzed the problem of determining the most favorable alternative route solution for the General project of the E 763 highway from Belgrade to the Southern Adriatic. The multi-criteria evaluation method (AHP method) was used. Objectives were defined, criteria and indicators were identified, and their weights were determined. Evaluation of proposed alternative solutions was conducted. The results showed that the "Center" variant is the most favorable solution for the route of the E763 highway project from Belgrade to the Southern Adriatic. Despite its undisputed quality, it should be emphasized that the success of applying the AHP method in the decision-making process largely depends on the capabilities and experience of the decision-maker. The decision-maker must be able to determine the importance of each criterion. The importance of impartially defining the weighting coefficients for individual criteria is particularly emphasized because the chosen solution is often not equally acceptable to the investor, the local community, or other stakeholders.

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