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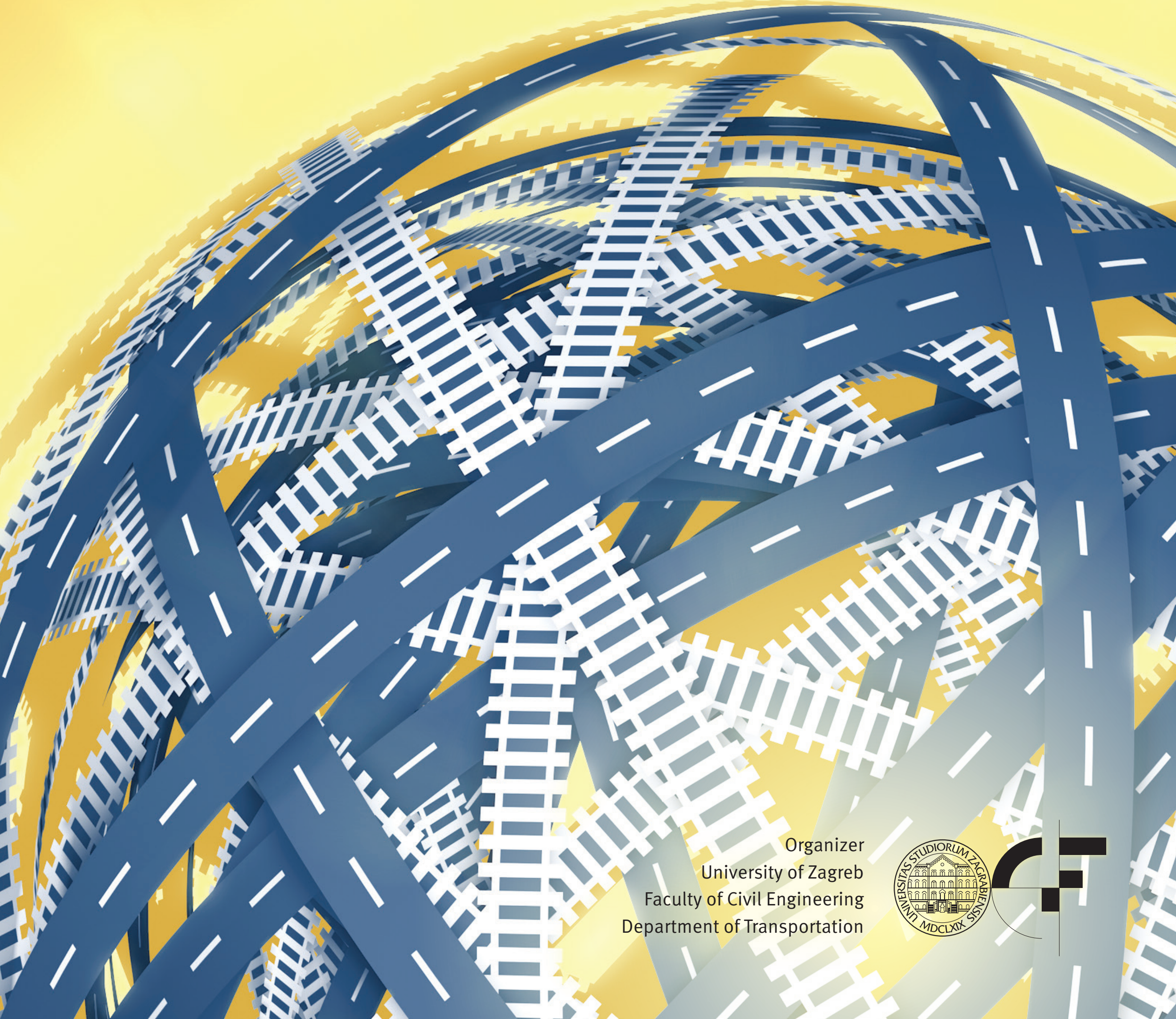
4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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ONE MODEL FOR RAIL PROJECTS EVALUATION WITH INTERVAL-VALUED FUZZY NUMBERS

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Abstract

Different heterogonous criteria have to be considered for rail projects evaluation process. Due to this fact many authors suggest applying the multicriteria decision making methods. Often in practice there is certain uncertainty and imprecision during the rail projects evaluation process. Fuzzy numbers are suitable for taking into account these characteristics of a model. We develop the model for rail projects evaluation using the interval-valued fuzzy AHP and interval-valued fuzzy TOPSIS. Model is tested on the real rail projects at Serbian rail network. The proposed approach is suitable for making the transport projects evaluation model, with consideration of all conditions at real transport market.

Keywords: Rail projects evaluation, Interval-valued fuzzy numbers, AHP, TOPSIS

1 Introduction

Multi-criteria methods for transport projects evaluation are suitable approaches because of the presence of many heterogonous criteria relevant in this process. When these criteria or their mutual relations are uncertain and imprecise the application of the fuzzy logic is suggested. Interval-valued fuzzy sets are an extension of fuzzy sets and provide more adequate description of uncertainty and imprecision than traditional fuzzy sets. Interval-valued fuzzy sets can be used when there is a problem in determining the exact membership values of the elements, so in that cases, the intervals are used as membership values.
Authors develop the model for rail projects based on the interval-valued fuzzy AHP and interval-valued fuzzy TOPSIS. The suggested model is based on real data from the project ("Rail Rehabilitation in Serbia: Technical Assistance for Railway Infrastructure" – Rail Master Plan in Serbia, EIB, 2012).

2 Methodology

The concept of interval-valued fuzzy sets was proposed by Gorzalczany [1]. In their paper, Yao & Lin [2] represented interval-valued fuzzy set. Fig. 1 shows the interval-valued triangular fuzzy number (IVTFN) $\bar{A}$ which consists of the lower triangular fuzzy number $\bar{A}^L$ and the upper triangular fuzzy number $\bar{A}^U$.

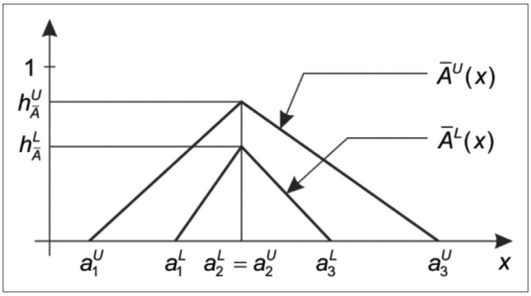

Figure 1 Interval-valued triangular fuzzy number

In order to represent the IVTFN shown above, following notation is used:

$$\bar{A} = \left[\left(a_1^L, a_2^L, a_3^L; h_{\bar{A}}^L\right), \left(a_1^U, a_2^U, a_3^U; h_{\bar{A}}^U\right)\right] \quad (1)$$

where $a_1^L, a_2^L, a_3^L, a_1^U, a_2^U, a_3^U$ are crisp values, and $0 \leq h_{\bar{A}}^L \leq h_{\bar{A}}^U \leq 1$. Chen [3] presented the arithmetic operations between IVTFNs.

With the aim of rail projects evaluation and ranking, this paper proposes two-stage analysis. In the first stage, the interval-valued fuzzy AHP (IVF-AHP) is used to determine the preference weights of evaluation [4]. In the second stage, using obtained preference weights by IVF-AHP, interval-valued fuzzy TOPSIS (IVF-TOPSIS) method is employed in order to improve the gaps of alternatives between real performance values and achieve aspiration levels [5] and to evaluate and rank rail projects observed.

2.1 The interval-valued fuzzy AHP

Considering shortcomings of pure AHP method, such as not taking into acount the uncertainty associated with the process involved [5], this paper proposes integration of fuzzy theory and AHP in order to improve the uncertainty, by using IVTFNs. The steps in IVF-AHP implemented in this paper are presented as follows:

Step 1: Building the evaluation hierarchy system for evaluating and ranking alternatives, considering criteria involved.

Step 2: Defining the linguistic variables for the pair-wise comparison of criteria in terms of importance. In this paper, seven linguistic variables are used in pair-wise comparison of criteria importance, as shown in Table 1.

Table 1 Linguistic variables for pair-wise comparison of criteria

Linguistic variable	IVTFN
Very High (VH)	[(6,7,8;0.9),(5,7,9;1)]
High (H)	[(5,6,7;0.9),(4,6,8;1)]
Medium High (MH)	[(4,5,6;0.75),(3,5,7;1)]
Medium (M)	[(3,4,5;0.75),(2,4,6;1)]
Medium Low (ML)	[(2,3,4;0.5),(1,3,5;1)]
Low (L)	[(1,2,3;0.5),(1,2,4;1)]
Very Low (VL)	[(1,1,1;1),(1,1,1;1)]

Step 3: Constructing the pair-wise comparison matrices among all the criteria in the dimensions of the hierarchy system, by assigning linguistic terms to the pair-wise comparisons.

Step 4: Determining fuzzy geometric mean by using geometric mean technique [6]. The fuzzy geometric mean is defined as:

$$\bar{r}_i = (\bar{c}_{i1} \times ... \times \bar{c}_{ij} \times ... \times \bar{c}_{in})^{1/n} \quad (2)$$

where $\bar{c}_{ij}$ is a IVTFN representing comparison value of dimension i to criterion j.

Step 5: Determining fuzzy weights of each criterion by:

$$\bar{w}_i = \bar{r}_i / (\bar{r}_1 + ... + \bar{r}_i + ... + \bar{r}_n) \quad (3)$$

2.2 The interval-valued fuzzy TOPSIS

Suppose MCDM problem has m alternatives (A_1,...,A_m) and n decision criteria (C_1,...,C_n). Each alternative is evaluated with respect to n criteria. Considering the fact that, in some cases, determining exact value for the elements of decision matrix is difficult, these values can be threated as fuzzy numbers [7]. The IVF-TOPSIS method applied in this paper consists of following steps:

Step 1: Determining the weighting of evaluation criteria by IVF-AHP.

Step 2: Constructing the fuzzy performance (decision) matrix using the appropriate linguistic variables for the alternatives with respect to the criteria:

$$\bar{D} = \left[\bar{x}_{ij}\right]_{m \times n} \quad ,i = 1,...,m;\ j = 1,...,n \quad (4)$$

Step 3: Determining the normalized fuzzy decision matrix:

$$\bar{R} = \left[\bar{r}_{ij}\right]_{m \times n} \quad ,i = 1,...,m;\ j = 1,...,n \quad (5)$$

by using the following formula:

$$\bar{r}_{ij} = \left[\left(\frac{(x_{ij})_1^L}{(x_j^+)_3^U}, \frac{(x_{ij})_2^L}{(x_j^+)_3^U}, \frac{(x_{ij})_3^L}{(x_j^+)_3^U}; h_{\bar{x}_{ij}}^L\right), \left(\frac{(x_{ij})_1^U}{(x_j^+)_3^U}, \frac{(x_{ij})_2^U}{(x_j^+)_3^U}, \frac{(x_{ij})_3^U}{(x_j^+)_3^U}; h_{\bar{x}_{ij}}^U\right)\right] \quad (6)$$

where $(x_j^+)_3^U = \max_i\{(x_{ij})_3^U \mid j = 1,...,n\}, i = 1,...,m;\ j = 1,...,n$.

Step 4: Determining the weighted fuzzy normalized decision matrix:

$$\bar{U} = \left[\bar{u}_{ij}\right]_{m \times n} \quad ,i = 1,...m;\ j = 1,...,n \quad (7)$$

where $\bar{u}_{ij} = \bar{r}_{ij} \times \bar{w}_j$.

Step 5: Determining the IVF positive-ideal solution (IVFPIS) and IVF negative-ideal solution (IVFNIS). Defining the aspiration levels and the worst levels as:

$$\bar{A}^+ = (\bar{u}_1^+, ..., \bar{u}_j^+, ..., \bar{u}_n^+) \quad (8)$$

$$\bar{A}^- = (\bar{u}_1^-, ..., \bar{u}_j^-, ..., \bar{u}_n^-) \quad (9)$$

where $\bar{u}_j^+ = [(1,1,1;1),(1,1,1;1)] \times \bar{w}_j$ and $\bar{u}_j^- = [(0,0,0;1),(0,0,0;1)] \times \bar{w}_j$, $j = 1,...,n$.

Step 6: Unlike the common practice in the fuzzy TOPSIS application, where the distance from positive ideal solution and negative ideal solution are identified (e.g. [5], [8]), this paper considers the degree of similarity $S \in [0,1]$, proposed by Chen & Chen [9]. The degree of similarity between each alternative and IVFPIS and IVFNIS is identified by:

$$S_i^+ = \sum_{j=1}^{n} S\left(\bar{u}_{ij}, \bar{u}_j^+\right) = \sum_{j=1}^{n}\left(1 - \frac{\sum_{k=1}^{3}\left|\left(\left(u_{ij}\right)_k^U - \left(u_{ij}\right)_k^L\right) - \left(\left(u_j^+\right)_k^U - \left(u_j^+\right)_k^L\right)\right|}{3}\right) \quad (10)$$

$$S_i^- = \sum_{j=1}^{n} S\left(\bar{u}_{ij}, \bar{u}_j^-\right) = \sum_{j=1}^{n}\left(1 - \frac{\sum_{k=1}^{3}\left|\left(\left(u_{ij}\right)_k^U - \left(u_{ij}\right)_k^L\right) - \left(\left(u_j^-\right)_k^U - \left(u_j^-\right)_k^L\right)\right|}{3}\right) \quad (11)$$

where $i = 1,...,m$. Two interval-valued fuzzy numbers $\bar{A}$ and $\bar{B}$ are identical if and only if $S(\bar{A},\bar{B}) = 1$.

Step 7: Considering that the degree of similarity is used in this paper instead of distance, the relative similarity is analogy defined instead of relative closeness. Relative similarity is calculated by:

$$R_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad ,i = 1,...,m \quad (12)$$

Step 8: Alternatives are ranked in terms of their relative similarity, where, in this case, the highest ranked alternative has the lowest relative similarity score.

3 Case study

The aim of this paper is evaluation and ranking of rail projects by methodology described. The nine projects observed in this paper are presented in Table 2.

Table 2 Rail projects included in the analysis

Alternative	Project
A_1	Beli Potok – Pancevo
A_2	Stara Pazova – HU Border
A_3	Stara Pazova – CRO Border
A_4	Rakovica – Velika Plana
A_5	Resnik – Trupale
A_6	Sicevo – BUG Border
A_7	Doljevac – MK Border
A_8	Resnik – ME Border
A_9	Pancevo – RO Border

Rail projects evaluation hierarchy system is presented in Fig. 2. The first level criteria consists of two criteria, while the second level criteria consists of six sub-criteria. The elements and the model structure are defined in the project – Rail Master Plan in Serbia. The two criteria within 1st level criteria are:

- C_1 – Strategic and functional indicators;
- C_2 – Social indicators.

The six sub-criteria are:
- C_{11} – Remove specific bottlenecks or other specific critical issues;
- C_{12} – Improve functionality and better connectivity;
- C_{21} – Number of inhabitants affected by the project;
- C_{22} – Cost / effectiveness;
- C_{23} – Market development (regarding unemployment rate);
- C_{24} – Economic feasibility (EIRR).

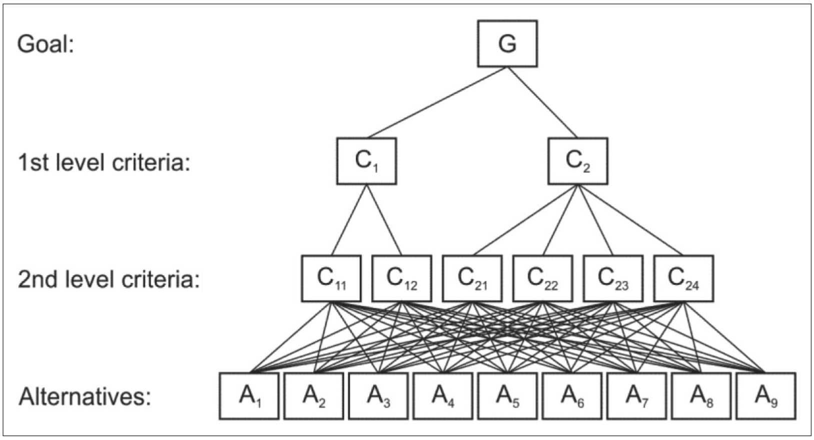

Figure 2 Rail projects evaluation hierarchy system

Regarding the importance of 1st level criteria, both criteria are considered as equally as important, thus having weights $w_1 = 0.5$ and $w_2 = 0.5$.The pair-wise comparison matrices among sub-criteria, determined using linguistic variables presented in Table 1, are:

$$\bar{C}1 = \begin{array}{c} \\ C_{11} \\ C_{12} \end{array} \begin{array}{c} \begin{array}{cc} C_{11} & C_{12} \end{array} \\ \begin{bmatrix} 1 & L \\ L^{-1} & 1 \end{bmatrix} \end{array} \qquad \bar{C}2 = \begin{array}{c} \\ C_{21} \\ C_{22} \\ C_{23} \\ C_{24} \end{array} \begin{array}{c} \begin{array}{cccc} C_{21} & C_{22} & C_{23} & C_{24} \end{array} \\ \begin{bmatrix} 1 & H^{-1} & MH & H^{-1} \\ H & 1 & MH & L^{-1} \\ MH^{-1} & MH^{-1} & 1 & H^{-1} \\ H & L & H & 1 \end{bmatrix} \end{array}$$

Based on Eqs. (2) and (3), fuzzy geometric mean and fuzzy weights of each sub-criterion are determined. Finally, since there are two criteria levels, final fuzzy weights which are used in second stage are obtained by multiplying fuzzy weights of sub-criteria with the weights of 1st level criteria (Table 3).

Table 3 Fuzzy weights of IVF-AHP process for each sub-criterion

Fuzzy weight	IVFN
$\bar{w}_{11}$	[(0.05,0.09,0.14;0.5),(0.05,0.09,0.18;1)]
$\bar{w}_{12}$	[(0.03,0.04,0,08;0.5),(0.02,0.04,0.09;1)]
$\bar{w}_{21}$	[(0.03,0.04,0.06;0.5),(0.02,0.04,0.07;1)]
$\bar{w}_{22}$	[(0.08,0.12,0.21;0.5),(0.06,0.12,0.25,1)]
$\bar{w}_{23}$	[(0.01,0.02,0.03;0.5),(0.01,0.02,0.04;1)]
$\bar{w}_{24}$	[(0.11,0.18,0.28;0.5),(0.09,0.18,0.36;1)]

The next step in the analysis is determining the decision matrix. While some values can be determined precisely, as a crisp value, some of them are rather uncertain, thus IVTFN are used. Values used in determining the decision matrix with regard to each sub-criterion are presented in Table 4.

Table 4 Values used in determining the decision matrix.

<table>
<tr><th>Sub-criteria</th><th>Value (Description)</th></tr>
<tr><td rowspan="2">C_{11}</td><td>0 (No)</td></tr>
<tr><td>1 (Yes)</td></tr>
<tr><td rowspan="4">C_{12}</td><td>1 (Between the sections of the TEN-T in Serbia and the EU TEN-T)</td></tr>
<tr><td>2 (Between sections of the TEN-T network in Serbia)</td></tr>
<tr><td>3 (Between sections of other international corridors in Serbia)</td></tr>
<tr><td>4 (Between local routes in Serbia)</td></tr>
<tr><td rowspan="3">C_{21}</td><td>[(0,0,400000;0.85),(0,0,500000;1)]
(Low Population – LP)</td></tr>
<tr><td>[(200000,500000,900000;0.85),(100000,550000,1000000;1)]
(Medium Population – MP)</td></tr>
<tr><td>[(700000,1100000,1100000;0.85),(600000,1100000,1100000;1)]
(High Population – HP)</td></tr>
<tr><td>C_{22}</td><td>amount|__|
(Value of investment / overall daily traffic at year 2017)</td></tr>
<tr><td rowspan="2">C_{23}</td><td>[(0,0,10.28;0.8),(0,0,11.28;1)]
(Low Unemployment – LU)</td></tr>
<tr><td>[(8.28,18.56,18.56;0.8),(7.28,18.56,18.56;1)]
(High Unemployment – HU)</td></tr>
<tr><td>C_{24}</td><td>%|__|
(Economic internal rate of return – EIRR)</td></tr>
</table>

Using values defined in Table 4, the performance of each alternative is evaluated with respect to each sub-criteria. The performance (decision) matrix for the alternatives with respect to each sub-criteria is:

$$
D = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \\ A_7 \\ A_8 \\ A_9 \\ \text{Objective} \end{array}
\begin{array}{cccccc}
C_{11} & C_{12} & C_{21} & C_{22} & C_{23} & C_{24} \\
1 & 2 & MP & 4.28 & LU & 12.56 \\
1 & 1 & MP & 7.53 & HU & 17.01 \\
1 & 1 & MP & 3.08 & LU & 13.15 \\
1 & 2 & HP & 8.88 & HU & 14.83 \\
1 & 2 & HP & 6.59 & HU & 17.35 \\
1 & 1 & MP & 4.99 & HU & 6.68 \\
1 & 1 & MP & 8.07 & HU & 8.6 \\
1 & 3 & MP & 19.00 & LU & 19.56 \\
0 & 3 & LP & 3.15 & LU & 7.37 \\
\max & \min & \max & \min & \max & \max
\end{array}
$$

Following the methodology described in Sec. 2, normalisation and weighting of decision matrix is conducted, and the aspiration levels are determined based on objective in terms of minimizing or maximizing. Finally, relative similarity scores and ranking of alternatives are presented in Table 5.

Table 5 Relative similarity scores and ranking of rail projects.

Alternative	Project	R_i	Rank
A_1	Beli Potok – Pancevo	0.498408	5
A_2	StaraPazova – HU Border	0.497405	2
A_3	StaraPazova – CRO Border	0.497898	3
A_4	Rakovica – Velika Plana	0.498220	4
A_5	Resnik – Trupale	0.497379	1
A_6	Sicevo – BUG Border	0.499484	8
A_7	Doljevac – MK Border	0.499397	7
A_8	Resnik – ME Border	0.498728	6
A_9	Pancevo – RO Border	0.501243	9

4 Conclusions

In this paper the model for rail projects evaluation is developed. In two-stage analysis authors use the interval-valued fuzzy AHP, to determine the preference weights of evaluation, and interval-valued fuzzy TOPSIS, to evaluate and rank rail projects. Interval-valued fuzzy sets are used in order to consider uncertainty and imprecision of inputs. The model is tested on the real rail infrastructure projects relevant for Serbian railways. Future researches will include more criteria and their mutual relations.

References

[1] Chen, S.H.: Ranking fuzzy numbers with maximizing set and minimizing set, Fuzzy Sets and Systems, 17, pp. 113-129, 1985.

[2] Chen, S.-M., Chen, J.-H.: Fuzzy risk analysis based on similarity measures between interval-valued fuzzy numbers and interval-valued fuzzy number arithmetic operators, Expert Systems with Applications, 36, pp. 6309–6317, 2009.

[3] Gorzalczany, M.B.: A method of inference in approximate resoning based on interval-valued fuzzy sets, Fuzzy Sets and Systems, 21, pp. 1-17, 1987.

[4] Hsieh, T.Y., Lu, S.T., Tzeng, G.H.: Fuzzy MCDM approach for planning and design tenders selection in public office buildings, International Journal of Project Management, 22, pp. 573-584, 2004.

[5] Kaya, T., Kahraman, C.: An integrated Fuzzy AHP–ELECTRE methodology for environmental impact assessment, Expert Systems with Applications, 38, pp. 8553–8562, 2011.

[6] Macura, D., Bošković, B., Bojović, N., Milenković, M.: "A model for prioritization of rail infrastructure projects using ANP", International Journal of Transport Economics, Vol. XXXVIII, No. 3, pp. 265-289, 2011.

[7] Macura, D., Nuhodžić, R., Bojović, N., Knežević, N.: "One model for rail infrastructure projects selection", CETRA, Dubrovnik, 7-9 May, Proceedings of papers, pp. 533-538, 2012.

[8] Mandic, K., Delibasic, B., Knezevic, S., Benkovic, S.: Analysis of the financial parameters of Serbian banks through the application of the fuzzy AHP and TOPSIS methods, Economic Modelling, 43, pp. 30–37, 2014.

[9] Mokhtarian, M.N., Hadi-Vencheh, A.: A new fuzzy TOPSIS method based on left and right scores: An application for determining an industrial zone for dairy products factory, Applied Soft Computing, 12, pp. 2496-2505, 2012.

[10] Vinodh, S., Prasanna, M., Hari Prakash, N.: Integrated Fuzzy AHP–TOPSIS for selecting the best plasticrecycling method: A case study, Applied Mathematical Modelling, 38,pp. 4662–4672, 2014.

[11] Yao, J.S., Lin, F.T.: Constructing a fuzzy flow-shop sequencing model based on statistical data, International Journal of Approximate Resoning, 29, pp. 215-234, 2002.